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A REVIEW OF CURRENT AND FUTURE ACTIVITIES IN SPACE

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By Addison M. Rothrock

National Aeronautics and Space Administration
Office, Program Planning and Evaluation

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INTRODUCTION

The purpose of this discussion is to give a general review of what we are doing in space and what we intend to do in space, and to discuss the problems we are solving and must solve to obtain our objectives. In so doing, we will also discuss why we have set these objectives.

First, what do we mean by space? We mean the universe beyond our Earth's atmosphere. Using this definition, the scope of space is infinite.

Much has been learned of space. During the third century, B.C., Eratosthenes of Alexandria made sufficient measurements to estimate the Earth's diameter as approximately 25,000 miles. In the next century, Ptolemy estimated the distance from Moon to Earth to be 59 times the radius of the Earth. Both figures are close to the truth. Following the decay and destruction of the Roman empire, the Greek learning was assimilated by the Arabs. By the ninth century, A.D., Baghdad had become a center of learning, and here the Arab astronomer Al-Battani added to the astronomical tables of Ptolemy.

The study of space was not undertaken to any great degree by our own developing Western Civilization until contacts were made with the Arabs through the Moorish invasions and through the Crusades. With the decline of the intellectual movement in the Islam world came the growth of it in our own. We term the first accelerative period of this growth the Renaissance. Started in the Italian penninsula by men such as Leonardo da Vinci and Galileo, the movement traveled to Northern Europe and to England. In the studies of the heavens we now have the names of Copernicus, Brahe, Kepler, Newton, and a host of others until, by the middle of our century, man had made extensive measurements of space and had learned much about it.

Visually, and with telescopes, we have been looking into space for many years. But other than light or radio waves, man had placed nothing in space until, on October 4, 1957, the Russian Sputnik was launched and the space age was in being. A summary of satellites and deep space probes successfully launched through March, 1959 is given in the appendix.

We are all more or less familiar with our own solar system (fig. 1) and its general dimensions (table I), and we know it is a very minute part of the galaxy we term the Milky Way (fig. 2[1]) and that, in turn, this galaxy is only one of many, many galaxies and clusters. We started our exploration of this vast universe of space with physical objects by means of payloads placed in space, immediate to our own planet. Our first step was to fire sounding rockets to altitudes of many miles (fig. 3). This was part of a study of our atmosphere and the space immediately around us. Following the sounding rockets, we come to the Earth satellite in which the vehicle is injected into space with sufficient velocity to give a centrifugal force equal to the Earth's gravitational pull. Next, we obtained injection velocities sufficient to overcome the Earth's gravitational pull and so permit our spacecraft to become a solar satellite. We will cause vehicles to come under the gravitational control of solar planets other than the Earth and to escape from our solar system.

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Basically, starting with Earth satellites, we provide an injection velocity sufficient to: (1) reach the satellite altitude desired, and (2) place the satellite into orbit at this altitude. The orbit may be circular or more generally elliptical (fig. 4). In this latter case (for which the circle is a particular solution) the closest approach to Earth is termed the perigee, and the greatest distance from Earth the apogee. The center of the Earth is one of the focii of the ellipse. As the injection velocity is increased, a value is reached at which the energy of the vehicle is sufficient to give an apogee at an infinite distance from the Earth. The vehicle path has now become a parabola, and the vehicle - as far as the Earth is concerned - does not return but travels off into space. Greater injection velocities result in the path becoming a hyperbola, with the excess over the parabolic velocity of interest in relation to the speed at which the vehicle leaves the Earth and the effect of other heavenly bodies on the vehicle travel.

We will review a few missions briefly and go into a more detailed discussion of the major problems to be overcome in developing adequate space vehicles or spacecraft, and then into a discussion of what we expect to accomplish by our flights into space. As a matter of terminology, that part of the vehicle which is to perform to specific mission - measure the Van Allen radiation belt, photograph the Moon, land on Mars - is termed the payload.

A procedure for placing a payload in an Earth circular orbit is shown in figure 5. Here a launching vehicle consisting of a three-stage chemical rocket system is used. The first two stages (more generally termed one-and-a-half stages) consist of the well-known Atlas system. The third stage is the Vega system. At launch the three Atlas rockets are fired. At about 50,000 to 100,000 feet the two large engines (each of 150,000-pound thrust) are dropped. Since during this altitude range the vehicle must work

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[1]Specific figure acknowledgments are given at end of paper.

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against air resistance as well as the Earth's gravity, the travel is nearly vertical during the first part of this period. Following dropoff of the booster, the third rocket (called here the sustainer) continues firing and the vehicle is brought to about a 30° angle with the Earth. At this point, the sustainer rocket and the now empty propellant tanks are dropped, leaving the Vega stage and the payload. The vehicle coasts to an altitude of 100 miles and an angle with the Earth's surface of close to 0°. The Vega rocket is now fired, increasing the velocity so that the stage with payload is accelerated and spirals from the Earth into an elliptical orbit with an apogee of 300 miles. At this point, the Vega rocket is fired again, giving a velocity increment sufficient to maintain a circular 300-mile orbit. The velocity of the vehicle, termed the injection velocity for a 300-mile circular orbit, is now 17,000 miles per hour. Since the vehicle is at an altitude at which the pressure of the Earth's atmosphere is virtually nil, it will stay in orbit a long time, making a complete revolution each $1\frac{1}{2}$ hour.

A more difficult mission is shown in figure 6; a payload is sent to the Moon. In this case the injection velocity is about 24,000 miles an hour. To place the vehicle in orbit around the Moon, the vehicle must have its velocity decreased some 1500 miles per hour, for a total velocity change by the rocket propulsion system of 26,500 miles per hour.

The velocity changes for leaving the Earth, landing on the Moon, taking off from the Moon, and returning to Earth are shown in figure 7. The total velocity change required is the sum of the values shown: 59,000 miles per hour. It is noticed that we refer only to the velocity changes required of the propulsion system. Actually, the magnitude or direction of the velocity is continually being changed by gravitational forces (even in an Earth circular orbit, there are small perturbations resulting from the effects of the other bodies in the solar system).

Representative velocity changes required of the propulsion system for different missions within our solar system as shown in figure 8. In a mission involving a return to Earth, a part of the required velocity change (about 17,000 miles/hr) is brought about by resistance of the Earth's atmosphere, rather than by the propulsion system. Since all other velocity changes listed must be produced by the propulsion system, we will review briefly the propulsion systems currently used and planned.

PROPULSION SYSTEMS

The purpose of a spacecraft propulsion system is to exert sufficient force for a sufficient time on the vehicle to cause the desired velocity change. To exert a force on a vehicle in space, mass (termed the propellant), or energy must be accelerated from the vehicle by the propulsion system. The system used currently is the chemical rocket (more specifically the chemical-thermal rocket), figure 9, in which two chemical compounds, a fuel and oxidant, are burned or a single chemical compound is decomposed. In either case, the chemical reaction results in high-temperature gaseous products (the propellant) which are accelerated to a high velocity, discharged by means of nozzle, and so produce the propulsive force. Since this propellant must be carried within the propulsion system (i.e., the vehicle), the total vehicle mass being accelerated at any moment includes all the propellant to be used subsequently. Continuously greater total vehicle weights at Earth launch are required to fly a given payload mass on increasingly severe missions. Or, putting it another way, a given total vehicle mass at launch is satisfactory for continually decreasing payloads as the mission velocity requirements are increased. This fact is illustrated in figure 10(a), in which different mission payloads in pounds are shown. A multistaged chemical propulsion system is used. In each case, the stage mass (i.e., weight at the Earth's surface) includes the mass of all the subsequent stages. Thus, the first stage less the subsequent stages weighs about 3,000,000 pounds. About 90 percent of this weight is the propellant (fuel plus oxidant). Using all stages, this vehicle could launch a 2000-pound manned capsule and bring it to a Moon landing. There would be sufficient mass allowance in addition to the capsule to provide a propulsion system to launch the capsule from the Moon and bring it back into an Earth orbit and to an Earth landing. A payload of 4500 pounds could be sent on a planet probe mission. For a soft Moon landing without return, a 20,000-pound payload could be used. A payload of 43,000 pounds could be placed in an Earth orbit at an altitude of 19,000 nautical miles. In this case, the time for a complete revolution would be 24 hours. A mass of 150,000 pounds could be placed in a 300-mile orbit. The respective ratios of takeoff weight (or mass) to payload mass are approximately 2500, 1000, 250, 100, and 30. Obviously, decreasing these ratios is desirable. These ratios will be decreased as the propellant specific impulse - that is, the thrust produced per pound of propellant discharged (accelerated) per second - is increased. The specific impulse is directly proportional to the velocity to which the propellant is accelerated. The major objective in propellant systems research is to increase this discharge velocity, that is, specific impulse. Increases can be obtained by using chemical propellants that yield higher combustion temperatures or, better yet, lower molecular weight combustion (propellant) gases. By using a nuclear reactor (fig. 9) in place of combustion as the heat source, the propellant need not be limited to combustibles. An extremely low molecular weight gas, say, hydrogen, can be used with a two to threefold increase in specific impulse. The nuclear reactor has a temperature limitation, the temperature limit of the materials of which the reactor is made.

The order of improvement over the values given in figure 10(a) that might be expected by using a second-stage nuclear rocket is shown in figure 10(b).

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If the particles (molecules) of the propellant gas are charged electrically (ionized), an electrostatic or electromagnetic force can be used to accelerate the propellant (fig. 11), and much higher velocities can be obtained than with the thermal rockets.

Chemical thermal rockets are in the use and development stage. Much research is being conducted on the chemical fuels and oxidants. Nuclear-thermal and nuclear-electric rockets are in the research stage. The more difficult missions, say, those requiring propulsion-system velocity changes of 60,000 miles or more, may well await the development of these nuclear propulsion systems.

The range of specific impulses presently being obtained, expected with the different systems, is shown in figure 12. Also listed are values of specific power; that is, the power that must be produced in the propellant jet for each pound of thrust produced. For the thermal rockets the specific power values are sufficiently low to be of secondary interest. However, with the electric rockets this power must be produced in the form of electricity. Electric-power-producing systems are not light. Until much progress is made in this field, the thrust for the nuclear-electric rocket system will be limited to values of about 0.0001 the mass of the spacecraft. As a result the electric systems are currently considered only for those portions of the flight in which gravitational forces on the vehicle are either of this same order in relation to the vehicle mass or are offset by the vehicle velocity. This rules out the use of the electric rockets for launchings from the planets. Figure 13 shows an artist's conception of a nuclear-electric-rocket-powered space vehicle, and figure 14 gives the time in days required to complete a flight from Earth orbit to Mars orbit and return to Earth orbit using a nuclear-electric rocket with a thrust-to-mass ratio of 0.0002, or a thermal (designated high thrust) rocket with a thrust of the same order as the vehicle mass. The differences in time result from the much slower acceleration rate with the electric rocket.

Summarizing, chemical-thermal rockets with increasing specific impulses are and will be the propulsion systems employed in spacecraft for several years to come. With successful completion of research on the nuclear-thermal and nuclear-electric rockets, missions not feasible with the chemical propulsion systems will be performed by these newer devices. The relative advantage between the nuclear-thermal and nuclear-electric rocket cannot be determined until additional research has been conducted on both.

GUIDANCE SYSTEMS

Obviously, for a spacecraft to be operated satisfactorily, it must be properly directed or guided. This guidance is done by a system capable of: (1) determining the position and velocity of the vehicle, and (2) from these determinations, making necessary changes in velocity magnitude or direction, to keep or place the vehicle on proper course. We are using the term "velocity" in its complete sense, that is, as a vector. Therefore, a change in velocity may result in a change in either velocity magnitude or velocity direction. To change the velocity of the vehicle, an appropriate force must be imposed on the vehicle. This force will be the resultant of that imposed by the propulsion system (including small guidance rockets or solar sails as part of the propulsion system) and such gravitational forces as are acting on the vehicle. Since the direction of operation of the propulsion-system force with respect to the vehicle is generally limited by mechanical reasons, means must also be provided to change the attitude of the vehicle, that is, the angle of the vehicle relative to the line of flight. The attitude of the vehicle can be changed either by the propulsion-system forces or by internal forces produced by changes of momentum within the vehicle (fig. 15). This change in momentum can be produced by a rotating body, a momentum wheel.

There are three major divisions (fig. 16) in the guidance requirements. The first is guidance during the injection process, that is, during the first several minutes of flight during which time the vehicle is put on course for the first phase of the flight. For missions in which precise control is not required over appreciable time intervals, this first-phase guidance may be the only one used. Examples are ballistic missiles, Earth-orbit satellites, simpler deep space probes. The second phase is that of midcourse navigation. The term is more or less self-explanatory; it corresponds to the navigation of a ship at sea when position and velocity are determined by fixes on the stars or the Sun. The third phase consists of that period of flight during which the vehicle is approaching its objective, say, another planet. In this case, the vehicle must be caused to: approach to within the desired distance of a planet, be placed in orbit about the planet, be caused to land on the planet. To a considerable extent the first and third phases are similar.

The simplest system from the standpoint of devices carried aboard the vehicle is a ground radio guidance system (lower part of fig. 17). In this case, the actual vehicle guidance is provided by changing the angle of thrust (from the propulsion system) with respect to the flight path. The required attitude measurement and control is either derived by means of a gyro system carried aboard the vehicle or from the ground radio device. The velocity and position of the vehicle are determined by means of reflection from the vehicle of the ground originating the radio waves. The results are fed into the guidance computer, and the necessary changes in guidance are determined. These are radioed to the vehicle receiver and passed on to the auto pilot for actuation either of rocket nozzle controls (steering actuators) or the fuel and oxidant control valves.

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The second system used for the injection guidance is termed inertial guidance (upper part of fig. 17). In this case contact with the ground is not required. Instead an inertial sensing unit is employed. This unit consists essentially of three accelerometers, each mounted on one of the three major axes of a gyro-stabilized platform; that is, a platform whose attitude, as a result of the gyros, remains stationary in space. The accelerometers indicate the resultants of the vehicle velocity changes. This information is forwarded to the guidance computer which, in turn, computes the vehicle position and velocity from a summation of the acceleration-time effects. The necessary control changes are computed and transmitted to the autopilot for actuation. Attitude is also determined by means of gyros. Combination of ground radio control and inertial guidance control can be, and is, used.

The advantage of the inertial system over the ground radio control is that contact with the ground is not necessary and the system is, therefore, independent of the distance from the ground. The disadvantages are fourfold: (1) The weight of the system is currently too great to permit its uses in the smaller vehicles, (2) the system is more complicated than the ground radio system with the consequent effects on reliability, (3) the system indicates changes in velocity only and can therefore indicate position changes only under conditions of changing velocity, and (4) imperfections in the gyros cause the gyro axis to drift so that the platform does not, in fact, stay stable. The errors so introduced are too small to cause concern during short periods of operation; but during long periods, as might be required with the low accelerations resulting with the electrical propulsion systems, these can be serious.

As the first two problems are overcome, the inertial system will probably for the most part replace the ground radio system. When the vehicle is in deep space and navigational guidance is required, either radio or celestial navigation can be used (fig. 18). In the radio system, a powerful transmitter and receiver is needed on the ground because of the distance involved. The general principles here are the same as discussed under the radio system for injection guidance. Vehicle attitude can now be measured in relation to the Sun, and a momentum wheel can be used to control attitude. The necessary velocity changes are obtained by means of small rocket motors. The power requirements, of course, become higher as the distance from the Earth becomes greater.

For celestial navigation in the solar system, six independent measurements of vehicle position and velocity must be made. There are several combinations of these. One system consists of making three successive readings of a single planet against its background of stars. In this case, as well as the other cases, these measurements must be referred to a known reference system, a gyro-stabilized platform in which the drift errors are compensated for by periodic fixes on known stars. Again, results of the measurements are fed to the computer and so to the control rocket or rockets.

With the terminal guidance system (fig. 19), it is assumed that the vehicle is now sufficiently close to the objective, another planet or a return to the Earth, so that optical sensors or radar can correctly guide the vehicle, in general reversing the injection process.

Some figures on required accuracies in injection velocities and angles and on required guidance systems are shown in figure 20. It must be remembered that these velocities of 3 to 7 miles per hour represent injection velocity accuracies of the order of a hundredth of a percent.

TRACKING

After means to keep the vehicle on course are insured, it is also desirable to be able to track the vehicle from the Earth. This can be done partially or wholly by one of three means: (1) optically, (2) by use of radar reflection, and (3) by means of radio transmission to the Earth from the vehicle. The simplest means is optical: In this case, a telescopic camera (fig. 21) of large aperture is used to photograph the vehicle path. The Baker-Nunn camera designed for satellite tracking has been used extensively at some thirteen global stations (fig. 22). The camera is effective when the camera is in the Earth's shadow, so that there is a high reflectivity of the Sun's rays from the vehicle to the Earth. The background of stars in the photograph permit a high degree of position accuracy and in-orbit calculation.

The use of radar beam reflection is not considered generally, except for tracking unknown satellites, because the use of radio transmission from the vehicle is more satisfactory. The procedure used with current satellites consists of using the interferometer principle to compare phases of signals received in separate antenna as mounted on well-established baselines. Such a system is used for tracking Vanguard. The location of these stations, termed Minitrack, and a typical installation is shown in figures 23 and 24. A similar method, termed Microlock, is also used.

Greater distances can be covered by the use of a large-parabolic-disk radar antenna such as the 250-foot disk at Jodell Bank in England or the 85-foot disk at Goldstone, California (fig. 25). Three such stations located as shown in figure 26 will give global coverage.

The research and development in the field of tracking lies generally in the field of electronics. For the vehicle transmission - tracking station receiving system, progress is required in both the transmitter and the receiver. For the transmitter, it is again as in the guidance systems largely a case of weight against reliability; the power output as a function of weight is of prime importance. Also stability control of the vehicle is important to permit the use of directional antennas.

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With the receiver, research and development are required to permit the receiver to convert signals of less power into usable data. This requires a decrease in the internal noise level of the receiver. The kind of improvement in tracking distances that is expected to result in tracking improvement in both transmitter and receiver for the Goldstone station is shown in figure 27.

An indication of the power requirements for different uses is shown in figure 28. Since these data are somewhat out of date, the ratios, rather than actual values, should be considered.

POWER GENERATION

The discussions of guidance and tracking have shown that electric power must be available on other than the simplest spacecraft. In our later discussions we will see that power is, and will be, required to operate research instruments aboard the craft. Although to date the power requirements have been limited to a few watts, the requirements will go to many kilowatts.

For the low-power, short-time demands chemical batteries can be used, as estimated in figure 29. For the longer times or higher powers, nuclear energy (including the solar battery) will be used.

The nuclear turboelectric system and the solar (photoelectric) cell are shown diagrammatically in figure 30. Additional systems of interest are shown in figure 31. Power in the low kilowatt range may be considered for these devices. The source of energy is nuclear. Efficiencies of these systems are low. Using emiconductors for the thermopile, efficiencies of the order of 5 to 8 percent are obtained. Efficiencies are important because of higher powerplant mass required with low efficiency.

SCIENCE IN SPACE

We have discussed what we mean by space, different space flight paths, spacecraft propulsion systems, and means for guiding and tracking the spacecraft. We will now discuss what we are doing and what we expect to do in space. The subjects to be discussed in this section are tabulated in figure 32. Scientific investigations in space have been started with payloads of a few pounds. We do not want to imply that these payloads will suffice. Instrumented capsules of several thousand pounds are currently planned.

The first area of discussion is geodesy, the study of the Earth. In this field more accurate mapping will be made of the location of key points on the Earth's surface. The shape of the Earth is being studied through satellites launched as part of the International Geophysical Year. The elliptical flight path of an Earth satellite shows certain perturbations resulting from the fact that the Earth is not a perfect sphere; this results in variations in the Earth's gravitational pull on the satellite. Results of calculations of the flight path of the Vanguard satellite (fig. 33) show that there is less bulging at the equator than was previously indicated. Also, there is a slight pear shape to the Earth that was not previously known. The data indicate the precision with which the measurements can be made. For understanding the nature of the Earth, this precision is necessary.

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With respect to studies of the atmosphere (fig. 34), there is much that we are learning, and there is much that we need to know. The makeup of the atmosphere at these high altitudes is extremely important in the study and development of communication systems and in the field of meteorology.

The extent to which the pressure of the atmosphere decreases with altitude is indicated in figure 34 as a fraction of the sea-level pressure (10^{-6}A, 2×10^{-10}A, etc.) to altitudes of 150 miles. Sounding rockets such as the Aerobee-Hi, which carries a payload of 150 pounds, are used to obtain these data. The pressure has been estimated from satellite data to the order of 300 miles.

As long as atmospheric measurements were dependent on bodies supported by the atmosphere, measurements were limited to 20- to 30-mile altitudes. Under these conditions the increase in atmospheric temperature to more than 1000° F at 100 miles and above was not known.

When the pressure and temperature of the atmosphere are known, it is desirable to define the molecular species existing. The change from the atmosphere we know, consisting largely of molecular oxygen (O_2) and nitrogen (N_2), is shown in figure 34. From these data the mean free path of the molecules can be computed. The fact that oxides of nitrogen occur and that these oxides and the oxygen are electrically charged (ionized) is important in understanding the actions taking place in communications and in the general phenomena of the air around us.

We have yet to investigate and catalogue the atmospheres of Venus and Mars and of the other more distant planets.

We come now to the ionosphere, that is, the spherical shell of charged gases that stretches from 40 miles to many thousands of miles above the Earth's surface (fig. 35). An immediate interest in the ionosphere as mentioned in discussing the atmosphere (of which the lower ionosphere is a part) is in its effect on radio communications; the manner in which the various layers cause radio waves of different frequencies

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to bounce between the Earth and layers and so give us world-wide radio is illustrated. The successively higher levels, E to F, allow passage of successively higher frequencies and shorter wave length. The ionosphere differs from day to night. At night the two F regions merge and the E regions become spotty. The ionosphere is affected by radiations from the Sun. The charge density varies with latitude and season. Information attained from sounding rockets is teaching us much of the ionosphere, but we must learn much more of its source and nature. Of the ionospheres of the other planets we know little.

Our discussion of the ionosphere is not complete without reference to the Van Allen, or great, radiation belt (fig. 36) discovered with the Explorer I satellite, and further explored with the Explorers III and IV and with the Pioneer II and III deep space probes. The information collected on these flights shows the need of further deep space exploration to catalogue these electromagnetic fields.

The investigation of energetic particles impinging on the Earth or absorbed in the ionospheres or atmosphere is indicated in figure 37. Included are cosmic rays that cause the aurora borealis, and the particles that form the Van Allen radiation belt. Within the last year, sounding rockets fired from Fort Churchhill in Canada showed that the auroras are produced by electron incident in the Earth's upper atmosphere. The great radiation belt has been discovered, but it is not understood. Exploration by means of sounding rockets and deep space probes will continue.

Beyond the environs of the Earth we have the study of magnetic fields in our solar system (fig. 38). We know some but want to know more about the Earth's magnetic field. We know that the Sun has a field and that it varies as does the Earth's magnetic field. Whether the other planets have magnetic fields, we do not know. We think there may be an intergalactic magnetic field, but we do not know. The answers to these questions must be obtained through future research.

Under the heading of gravity we will discuss an experimental check on a portion of Einstein's theory of relativity - the effect of a gravitational field on the time to complete a physical process. According to relativity theory, if we have two identical clocks, one operating in the gravitational field at the Earth's surface and the other operating in a gravity-free or near-gravity-free location, the latter clock will run faster than the former (fig. 39). Two identical atomic clocks indicated as the Earth clock and far-satellite clock (in a 4000- to 5000-mile orbit) may be used in the experiment. An accuracy of about 10^{-11} will be required. The left-hand clock, marked near-satellite clock, indicates certain difficulties in the experiment as a result of which, if the satellite is too close to the Earth, an opposite effect may be observed.

The general field of astronomy (fig. 40) is the subject of much research and requires a great deal more information to help us understand the universe in which we live. In discussing the ionosphere, we brought out the fact that it obstructs the passage of certain radiations. Observations of the planets or the stellar systems made from the Earth are limited to those radiations that are transmitted through the ionosphere and the atmosphere (fig. 41). By mounting a telescope on a satellite as illustrated in figure 40, the part of the spectrum now barred to us will become available. This will include information in the X-ray and gamma-ray range and in that portion between visible light and the radio waves - that is, representative of molecular reactions - of the radiations occurring in life chemistry. This general field of astronomy has been marked by: (1) visual observation, (2) optical telescopic observation, (3) radio telescopic observation, and now will be marked by another major step forward, observation outside the Earth's atmosphere.

We now come to the study of biology and, in general, the life sciences in space. Various factors are tabulated in figure 42. These studies will involve the actions of space environment on plant life, living cells, animals, and on man himself. It will also include the study of possible life on other planets. This field has scarcely been touched.

APPLICATIONS OF SPACE TECHNOLOGY

We will consider applications of space technology that will be of immediate benefit to us. Meteorological satellites and communications satellites will be discussed.

In 1954 meteorologists were able for the first time to form a picture of a storm as seen from the sky above the storm. This picture, a composite (fig. 43) constructed by the staff of the U.S. Weather Bureau from several hundred photographs, was taken from an Aerobee sounding rocket at a 100-mile altitude. The picture covers the southcentral and southwestern part of the United States. The hurricane that is clearly visible was not seen or recorded from ground stations. Because of its height, the winds measured from the ground were not great, but the flooding rains were. We want to take weather records from altitudes greater than 100 miles for greater coverage. We want to make the kinds of measurements listed in figure 44. These include measurements of heat balance, temperatures, and air constituents, as well as observations of the clouds themselves. This information will not solve our weather problems, but it will lead to a better understanding and more accurate and longer range weather forecasting with resultant economic savings.

By using a meteorological satellite system similar to that shown in figure 45, world-wide weather reporting can be obtained. In this case, several polar orbit or quasi-polar orbit satellites are used in conjunction with "stationary" (i.e., 24-hr orbit) satellites at a 22,000-mile altitude.

Turning to communications satellites, the simplest is the passive satellite (fig. 46). In this case, the satellite consists of a large sphere or other reflecting body. Radio waves from the ground station are directed to the satellite and are reflected by the satellite back to ground. High-powered ground transmitter and sensitive receivers are required, since there is no amplification between the ground transmitter and ground receiver. The passive system has the advantage that no instrumentation is required within the satellite and it can be used by any transmitting or receiving station of the appropriate power levels and sensitivity. The NASA plans later this year, as an example, to launch a 100-foot-diameter aluminized plastic balloon weighing 65 pounds in orbit at 1000 miles altitude for such a communications satellite.

The second type of communications satellite is one that contains within it a receiving and broadcasting system. In this case, the transmission from the ground is received by the satellite and retransmitted to the ground (fig. 47). A "round-the-world" system is shown in figure 48. In this case, three "stationary" (22,000-mile-altitude equatorial orbit) satellites are shown. The program is transmitted to the receiver and rebroadcast to ground. A second ground system can receive and rebroadcast the program to a second active satellite, or receiving and broadcasting could be directly between satellites. With the three-satellite system shown, programs can be televised around the world. Such a system requires development in electronics and in power-producing equipment within the satellite suitable for trouble-free operation over several years. The Project Score satellite (see appendix) was the first example of an active communication satellite.

Meteorological and communication satellites should be in use within a few years.

MAN IN SPACE

We now come to the last part of our discussion, our most ambitious program: putting a man in space. Our reasons for so doing are that it is a necessary part of our technological progress; and, further, to adequately make explorations in space - including the explorations of other planets - we must have man, with his intellect and his ability to reason, take an intimate part in the explorations.

We will describe certain activities in the United States relative to man-in-space. The problem of reentry into the Earth's atmosphere is encountered, as well as the greater systems reliability demanded. The major problem on reentry is that of heating from high-speed passage through the air. All but a few percent of the kinetic energy resulting from the satellite velocity must be absorbed by the atmosphere to permit satisfactory reentry, but the remaining few percent produces serious problems.

If the reentry is rapid, the rate of heat absorption is high, and rate of absorption is of major importance. Representative values are shown in figure 49 for different reentry forms. The absorbed heat might be taken care of (1) by a high-specific-heat (i.e., low-molecular-weight) metal such as beryllium, (2) by ablation, that is, by actual melting or sublimation of the material, or (3) if the rate is sufficiently low, by radiation. The problem of material strength at high temperatures must be considered for various vehicle parts. Comparative values for several materials are indicated in figure 50.

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The first United States attempt to place man in the fringes of space will be made with the X-15 (fig. 51), which will be launched from a B-52 airplane. A representative flight plan in which the total rocket impulse is used to give the plane velocity and altitude is shown in figure 52. Following rocket burnout, the plane coasts to its maximum altitude and then returns to Earth in a glide.

The United States hopes to place a man in an Earth orbit in 1961. The date will, of course, be dependent on the success of the necessary preliminary experiments. The capsule in which the man will be placed (fig. 53) will be mounted on an Atlas booster system (fig. 54). The escape system is supplied with rockets to eject the capsule from the booster if trouble is encountered during the launching period.

In the flight trajectory (fig. 55) the Atlas booster and sustainer will launch the capsule with sufficient velocity to inject it into an Earth orbit at which time the Atlas sustainer propulsion system, together with propellant tanks and necessary structure, are separated from the capsule. The booster rockets will have dropped off earlier. The capsule, after a few orbits, will be slowed down by retrorockets and so caused to lose altitude and reenter the Earth's atmosphere. The aerodynamic drag will continue the deceleration and loss of altitude of the capsule until such time as the parachute may be released by the final deceleration and landing. Assuming a successful three-orbit mission, the flight path will be as shown in figure 56 with an ocean landing. These first United States flights of man-into-space will provide information on man's ability to cope with the problems encountered in space.

Additional research and development is required to permit controlled landing of space vehicles at specific locations on the Earth. Such devices (fig. 57) will provide aerodynamic control.

As more ambitious manned flights are planned, larger rocket booster systems will be needed to inject the manned payload. Figure 58 gives an idea of the gross weight at takeoff for a series of manned operations. Phase IV is the NASA Nova system already shown in figure 10. A conception of a large space laboratory is shown in figure 59. These are the kinds of things we expect to put into space, and with them continue man's quest for knowledge and self-betterment.

ACKNOWLEDGMENTS

A discussion of the sort presented herein obviously requires the assistance of many people both in preparation of the text and in preparation of the figures. For this assistance, I have drawn heavily on the technical staff of the NASA. All figures except those specifically acknowledged below were prepared in conjunction with various NASA lectures and presentations and are not given specific credit acknowledgment. In preparing the discussion, two documents were particularly useful. It is noted that both are related to technical presentations before committees of the Congress of the United States. These documents are:

1. Space Handbook: Astronautics and Its Application. Staff report of the Select Committee on Astronautics and Space Explorations, United States House of Representatives 85th Congress, Second Session.

2. Hearings before the NASA Authorization Subcommittee of the Committee on Aeronautical and Space Sciences, United States Senate 86th Congress, First Session; Part I. Scientific and Technical Presentations.

Figure Acknowledgements:

Figures 1, 4, and 41: From reference 1 above.

Figure 2 (upper): Code, Dr. Arthur D., and Houck, Theodore E., University of Wisconsin.

Figure 2 (lower): Wilson, James Perry, American Museum of National History, New York, N.Y.

Figure 8: Sutton, George P.: Rocket Propulsion Systems for Interplanetary Flight, The 1959 Minta Martin Lecture, Institute of Aeronautical Sciences.

Figures 15 to 25, 20, and 27: Jet Propulsion Laboratory, California Institute of Technology.

Figure 29: Aerojet-General Corporation.

Figure 43: United States Weather Bureau.

Figure 51: North American Aviation Corporation.

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APPENDIX - UNITED STATES AND RUSSIAN VEHICLES LAUNCHED INTO EARTH ORIBTS OR DEEP SPACE THROUGH MARCH, 1959[a]

[Official statistics prepared by the National Aeronautics and Space Administration]

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee, miles	Apogee, miles
SPUTNIK I Russia Satellite (sphere) Estimate of total payload weight in orbit: about 4 tons (unofficial) Scientific instrumentation in payload: 184 lb	Oct. 4, 1957 to Jan. 4, 1958	Not disclosed	Dimensions: 22.8 in. in diam. Experiments: internal temperatures, pressures, and "other data." Shell composition: aluminum alloys. Antennas: 4 spring-loaded whip antennas, 4 ft, 10.5 in. to 9 ft, 6 in. Transmitters: (a) 20,005 mc; (b) 40,002 mc. Power supply: Chemical batteries. Transmitter lifetime: (a) and (b) stopped Oct. 27, 1957	Period: 96.17 min; speed (perigee): 18,000 mph; speed (apogee): 16,200 mph. Inclination to Equator: 65 deg	142	588
SPUTNIK II Russia Satellite (complex) Estimate of total payload weight in orbit: about 4 tons (unofficial) Scientific instrumentation in payload: 1120 lb	Nov. 3, 1957 to April 14, 1958	Not disclosed	Dimensions: (not disclosed). Experiments: cosmic rays; solar ultraviolet and X-radiation; test animal "Laika" (dog); temperatures; pressures. Shell composition: aluminum alloys. Antennas: (not disclosed) Transmitters: (a) 20,005 mc; (b) 40,002 mc. Power supply: Chemical batteries. Transmitter lifetime: (a) and (b) stopped Nov. 10, 1957.	The available acceleration of this satellite led to the discovery of significant solar influence on upper atmosphere densities. Period: 103.7 min; speed (perigee): 18,000 mph; speed (apogee): 15,000 mph. Inclination to Equator: 65 deg	140	1038
EXPLORER I United States Satellite (cylinder) Total payload weight in orbit: 30.8 lb Scientific instrumentation in payload: 18.13 lb	Jan. 31, 1958 (Estimated lifetime: 3 to 5 years)	U.S. Army Jupiter C Stages: 4 1st: Elongated Redstone (liquid) 2nd: Scaled-down Sergeant rockets (solid) 3rd: Scaled-down Sergeant rockets (solid) 4th: Single scaled-down Sergeant (solid) Height: 68.6 ft	Dimensions: 80 in. long, 6 in. in diam. Experiments: cosmic rays; micrometeorites: (a) microphone, (b) gauges; temperatures: internal, rear skin, front skin, and nose cone. Shell composition: steel with 8 aluminum oxide strips. Antennas: 1 turnstile antenna with 4 whip elements each 22.5 in. long, and 1 dipole antenna using skin of satellite itself. Transmitters: (a) 108 mc at 10 mw and (b) 108.03 mc at 60 mw Power supply: mercury batteries Transmitter lifetime: (a) stopped May 23, 1958; (b) stopped Feb. 11, 1958, began again Feb. 24, stopped finally Feb. 28, 1958.	Explorer I is credited with what is probably the most important satellite discovery of the International Geophysical Year, i.e., a radiation belt around the Earth identified by Dr. James A. Van Allen, head of the University of Iowa Physics Department. A second belt was discovered later by Pioneer III. Period: 114.8 min. Inclination to Equator: 33.34 deg	224	1573
VANGUARD I United States Satellite (sphere) Scientific payload and total weight in orbit: 3.25 lb (Also in orbit: 50-pound 3rd-stage rocket casing)	March 17, 1958 Estimated 200 to 1000 years	Same as Test Vehicle 3	Dimensions: 6.4 in. in diam. Experiments: Temperatures and geodetic measurements. Shell composition: aluminum. Antennas: 1 turnstile antenna and 1 dipole antenna with total of six 12-in. rod elements. Transmitters: (a) 108 mc at 10 mw; (b) 108.03 mc at 5 mw. Power supply: (a) mercury batteries; (b) six groups of solar converters. Transmitter lifetime: (a) ceased operating April 5, 1958; (b) will operate indefinitely.	should transmit indefinitely. The Army Map Service has been making vice has been making electronic observations of the satellite from Pacific islands to pinpoint their location more exactly. The satellite is also being used for more exact determination of the Earth's shape.	409	2453
EXPLORER III United States Satellite (cylinder) Total payload weight in orbit: 31.0 lb Scientific instrumentation payload: 18.56 lb	March 26, 1958 to June 27, 1958	U.S. Army Jupiter C (Same as Explorers I and II)	Dimensions: 80 in. long; 6 in. in diam. Experiments: cosmic rays with tape-recorder feature; micrometeor gauges; temperatures: (a) skin and (b) internal. Shell composition: Steel with 8 aluminum oxide strips. Antennas: 2 dipole antennas using skin of satellite itself. Transmitters: (a) 108 mc at 10 mw; (b) 108.03 mc at 60 mw. Power supply: mercury batteries. Transmitter lifetime: (a) telemetering and beacon signal stopped May 10, 1958; beacon transmitted again May 15 to June 16; (b) first stopped May 14; responded erratically May 22 to June 5, 1958.	Explorer yielded valuable data on the radiation belt discovered by Explorer I as well as data on micrometeor impacts (density of cosmic dust) and internal and external temperature of the satellite. Period: 115.87 min Inclination: 33.4 deg	121	1746

[a]Except for VANGUARD II and PIONEER IV, and the Russian figures, all statistics listed are official. Statistics on VANGUARD II and PIONEER IV are subject to updating when study of data has been completed.
All distances are given in statute miles above surface of Earth.
Except where indicated, this chart does not include description and weights of spent rocket casings, etc., that have gone into orbit or flight trajections along with payloads.

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee, miles	Apogee, miles
SPUTNIK III **Russia** **Satellite** **(conical)** **Total payload weight in orbit: about 7000 lb (unofficial)** Scientific instrumentation payload: 2925 lb	**May 15, 1958** **Estimated lifetime: 15 months**	Not disclosed	Dimensions: 11 ft, 9 in. long; 5 ft, 8 in. wide at base. Experiments: atmospheric pressure and composition; concentration of positive ions; satellite's electrical charge and tension of Earth electrostatic field; tension of Earth's magnetic field; intensity of Sun's corpuscular radiation; composition and variations of primary cosmic radiation; distribution of photons and heavy nuclei in cosmic rays; micrometeors; temperature measurements. Shell composition: aluminum alloys. Antennas: folded dipole antennas and trailing rod antennas. Transmitters: 20.005 mc (transmission at 40.01 mc is harmonic of 1st). Power supply: (a) chemical batteries; (b) solar batteries.	**Period: 106 min. Speed (perigee): 18,837; speed (apogee): 14,637. Inclination to Equator: 65.3 deg**	135	1167
EXPLORER IV United States Satellite (cylinder) Total payload weight in orbit: 38.4 lb Scientific instrumentation in payload: 25.8 lb	July 26, 1958 Expected lifetime: about 1 yr	Same as Explorer I	Dimensions: 80.39 in. long; 6.25 in. in diam. Experiments: 2 Geiger-Mueller counters and 2 scintillation counters to measure corpuscular radiation at several intensity levels. The sub-carrier oscillator was calibrated to give internal temperature measurements. Shell composition: stainless steel. Antennas: 2 dipole antennas using the skin of the satellite itself. Transmitters: (a) 108 mc at 10 mw; (b) 108.03 mc at 24 mw (each transmitter broadcasts all five channels of information simultaneously and continuously. The first transmitter is primarily for tracking. Power supply: Mercury batteries. **Transmitters lifetime: Sept. 3, 1958: Telemetry on channels 2 and 5 cease. Sept. 9, 1958: 108.00-mc transmitter ceased operation Sept. 19, 1958: last intelligible telemetry on 108.03-mc transmitters. Oct. 6, 1958: 108.03-mc transmitter ceased.**	Same as Explorer I and III, i.e., valuable data on radiation belts, etc. Period: 110.27 min Inclination to Equator: 50.29 deg	163	1380
PIONEER I United States Lunar Probe (Toroidal) Total weight in flight: 84.4 lb, including 43.7 lb verniers and retrorockets. Scientific instrumentation in payload: 39 lb	Oct. 11 to Oct. 12, 1958 or 43 hr, 17 1/2 min	Thor Able I	Dimensions: 29 in. in diam., 30 in. long. Experiments: measurements of radiation in space; magnetic fields of Earth and Moon; density of micrometeor matter; internal temperatures; electronic scanner. Shell composition: fiber glass. Antennas: two 12-in. whips. Transmitter: (a) 108.06 mc at 300 mw (telemetry and Doppler command); (b) 108.06 mc at 1 watt (controls). Power supply: mercury batteries. Transmitter lifetime: 10 days.	Reentered atmosphere over South Pacific Oct. 12, 1958. (a) Determination of radial extent of radiation band. First observation that radiation is a band. (b) Mapped total ionizing flux. (c) First observation of hydromagnetic oscillations of magnetic field of Earth. (d) Discovered departure of magnetic field from theoretical prediction. (e) First determination of the density of micrometeors in interplanetary space. (f) First measurements of the interplanetary magnetic field.	**Altitude: about 70,700 statute miles**	
PIONEER III United States Space Probe (conical) Total weight in flight and scientific payload: 12.95 lb	Dec. 6 to Dec. 7, 1958 or 38 hours, 6 minutes after launch	Juno II stages: 4 1st: Jupiter (liquid) 2nd: 11 clustered Sergeants (solid) 3rd: Three clustered Sergeants (solid). Gross takeoff weight: 121,000 lb	Dimensions: 23 in. long; 10 in. maximum diam. Experiments: Measurement of radiation in space. Shell composition: gold-washed fiber glass. Antenna: Cone itself serves as antenna; gold is conductor. **Transmitters: 960.05 mc at 180 mw.** **Power supply: mercury batteries.** **Transmitter lifetime: 90 hr**	Discovered second radiation belt around Earth. Reentered atmosphere over French Equatorial Africa on Dec. 7, 1958. Designed velocity: 24,897 mph. Attained velocity: about 24,000 mph.	**Altitude: 63,580 miles**	
PROJECT SCORE (Atlas) United States Satellite Total weight in orbit: 8750 lb Scientific instrumentation in payload: 150 lb	Dec. 18 1958 to Jan. 21, 1959	WS107A-1 (Atlas) Powerplant: 2 boosters (approx. 150,000 lb each) and 1 sustainer engine (all liquid) plus 2 verniers. Gross takeoff weight: about 244,000 lb. Height: 85 ft Diameter: 10 ft	Dimensions: 85 ft long, 10 ft in diam. Experiments: Twin packages of radio transmitting, recording and receiving apparatus, each weighing 35 lb. Other components included a battery, a voltage converter, radio beacon, and a control unit. Shell composition: Stainless steel. Antennas: Slot type, flush with body of the Atlas. Transmitters: FM, 132.435 mc and 132.905 mc. **Minitrack signals: 107.97 mc and 107.94 mc.** Power supply: Mercury batteries. Transmitter lifetime: 12 days.	First time a human voice has been beamed from outer space. Message from President Eisenhower recorded and transmitted. Satellite accepted and relayed messages from ground stations in Texas, Arizona, and Georgia. Came down in vicinity of Midway Island in Pacific Ocean. Initial period: 101.46 min Inclination: 32.3 deg	110	920

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Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee, miles	Apogee, miles
LUNIK or MECHTA[b] (Dream) Russia Space Probe (sphere) Total weight in flight: 3245 lb	Jan. 2, 1959 (Believed to be in orbit around Sun)	T-3 Stages: 3 Speculated total thrust: 580,000 lb Height: 110 ft	Dimensions: (Not disclosed) Experiments: Instruments to measure temperature and pressure inside vehicle; instruments to study gas components of interplanetary matter and corpuscular radiation of the Sun; magnetic fields of Earth and moon; meteoric particles in space; heavy nuclei in primary cosmic radiation and other properties of cosmic rays. Shell composition: Pentagonal strips of stainless steel made of two hermetically sealed shells of aluminum-magnesium alloy. Antennas: (not disclosed). Transmitters: 3; (a) 19.997 mc and 19.995 mc signals of 1.6 sec duration, (b) 19.993 mc signals of 50.9 sec duration, (c) 183.6 mc	In orbit around Sun on 15-month cycle.		
VANGUARD II United States (sphere) Total weight in orbit and scientific instrumentation: 20.74 lb	Feb. 17, 1959 Expected lifetime: 10 yr or more	Vanguard Rocket (Same as Test Vehicle 3)	Dimensions: 20 in. in diam. Experiments: cloud cover. Shell composition: highly polished silicon-monoxide-coated magnesium. Antennas: 4 metal rods. Transmitters: (a) 108.00 mc at 10 mw; (b) 108.03 mc at 80 mw triggered from ground. Power supply: mercury batteries. Transmitter lifetime: (a) 23 days (b) 27 days. Satellite contained two photocells designed to produce crude images of cloud cover for 2-week period.	Period: 125.85 min Inclination to Equator: 32.88 deg In general, the satellite and its instrumentation functioned as planned. However, interpretation of data has been difficult because satellite developed a wobbling (precessing) motion.	347	2064
PIONEER IV United States (conical) Total weight in flight and scientific instrumentation: 13.40 lb	March 3, 1959 In orbit around Sun	JUNO II (Same as Pioneer III)	Dimensions: 20 in. long; 9 in. in diam. Experiments: Measurement of radiation in space. Test photoelectric sensor in vicinity of Moon. Shell composition: gold-washed fiber glass. Antenna: cone itself serves as antenna; gold is conductor. Transmitter: 960.05 mc at 180 mw with three subcarriers. Power supply: mercury batteries. Transmitter lifetime: about 90 hr	Probe achieved its primary mission, an Earth-Moon trajectory, yielded excellent radiation data, and provided a valuable tracking exercise. It is now orbiting the Sun. While the probe reached the vicinity of the Moon, it did not come close enough (20,000 miles) to trigger photoelectric sensor or sample Moon's radiation. The probe passed within 37,300 miles of Moon at 5:24 p.m. on March 4, 1959. It passed 7.2 degrees East and 5.7 degrees South of Moon at 4,490 mph. Probe reached perihelion, 91.7 million miles, at 9 p.m. March 17, 1959; scheduled to reach aphelion, 106.1 million miles on Oct. 1, 1959. Injection velocity of 24,790 mph was 188 mph below planned velocity. Pioneer IV was tracked for 82 hr to distance of 407,000 miles.		

[b]These are unofficial figures culled from U.S. press, Pravda, and Moscow radio.

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TABLE I. - PHYSICAL DATA OF SOLAR BODIES

Body	Mean distance to Sun × Earth's distance	Diameter, miles	Solar orbital velocity, miles/hr	Mass × Earth's mass	Length of year	Gravitational force at solid surface, g's	Number of moons
Sun	-----	864,000	-------	329,000	--------	----	--
Mercury	0.39	3,100	107,000	≈0.05	88 days	≈0.3	0
Venus	.72	7,500	78,000	.82	225 days	.91	0
Earth	1.00	7,920	67,000	1.00	365 days	1.00	1
Moon	1.00	2,160	[a]2,200	.012	365 days	.17	0
Mars	1.52	4,150	54,000	.11	1.9 yr	.38	2
Jupiter	5.2	87,000	29,000	317	12 yr	----	12
Saturn	9.5	71,500	22,000	95	29 yr	----	9
Uranus	19.2	32,000	16,000	15	84 yr	----	5
Neptune	30	31,000	12,000	17	165 yr	----	2
Pluto	39	?	11,000	.8	248 yr	----	?

[a]Earth's orbital velocity.

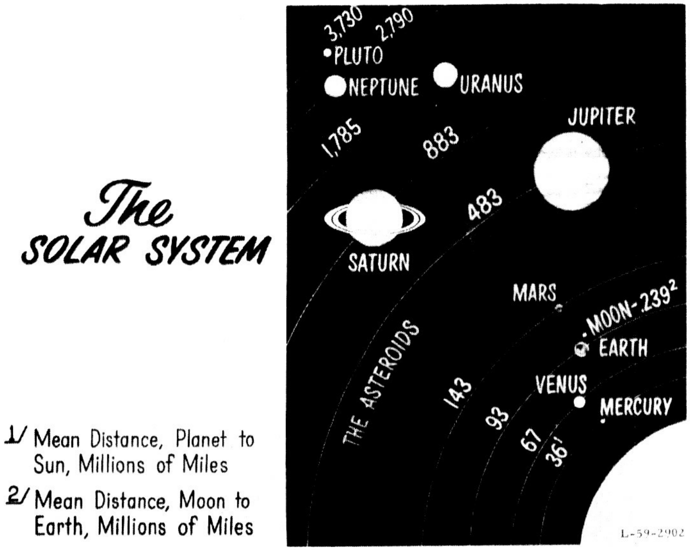

Figure 1.

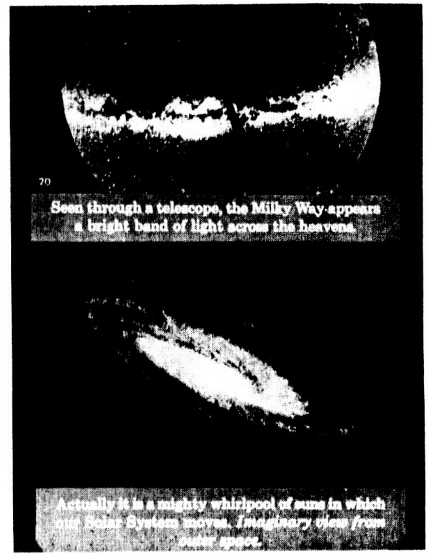

Figure 2.

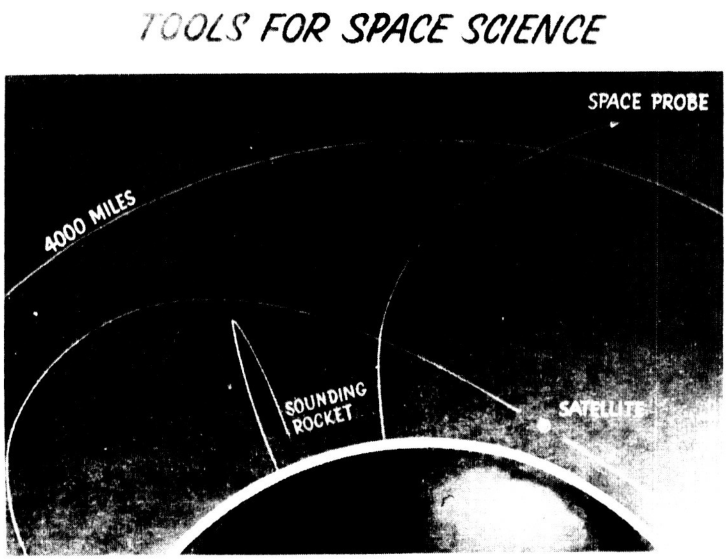

Figure 3.

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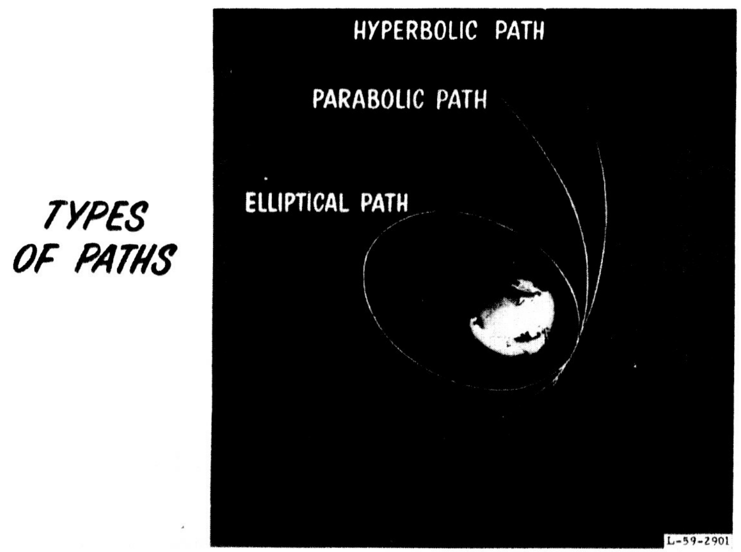

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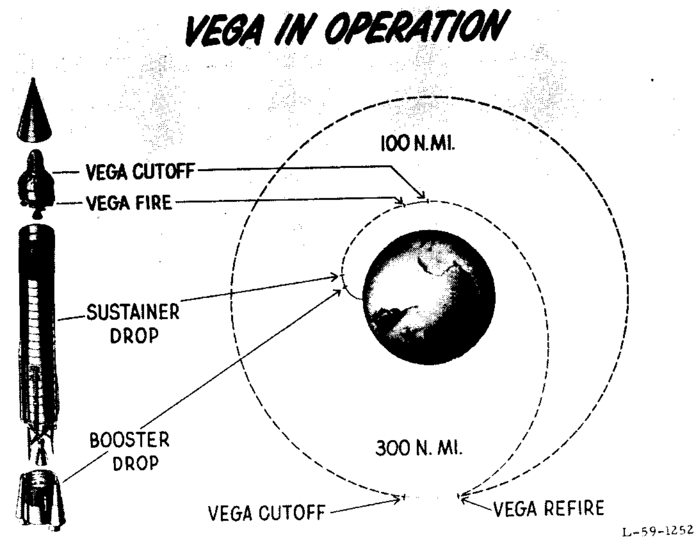

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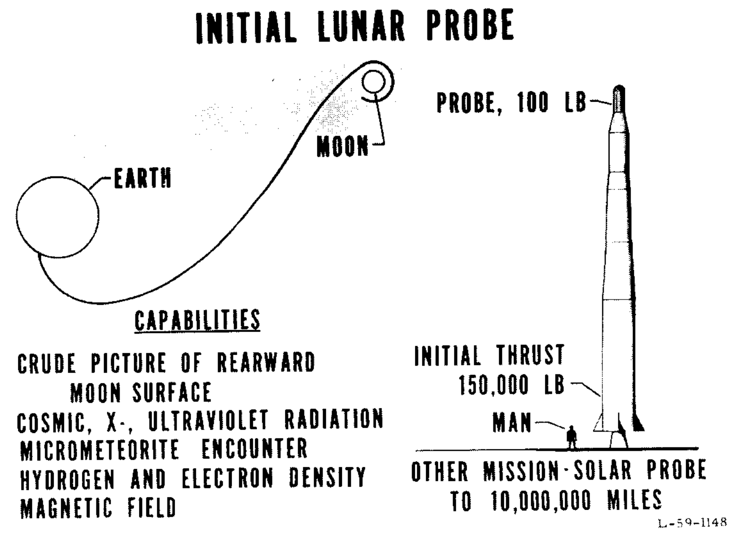

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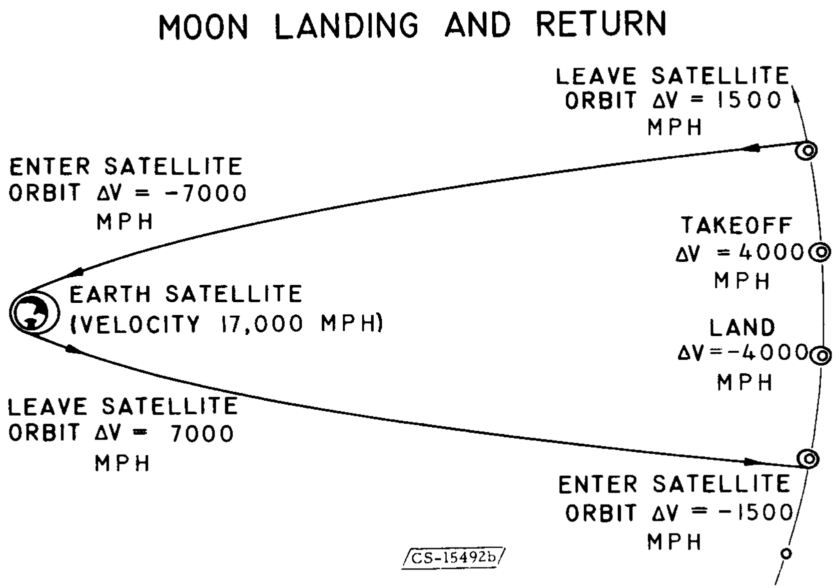

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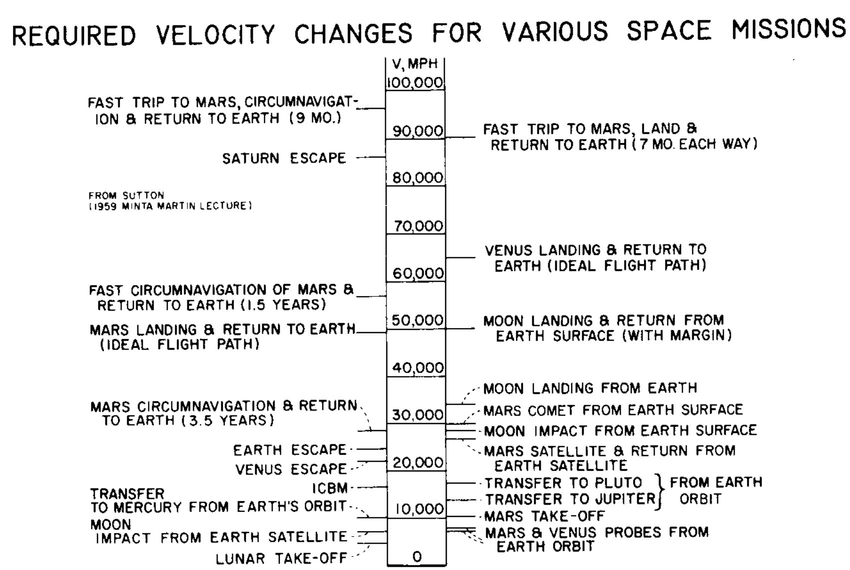

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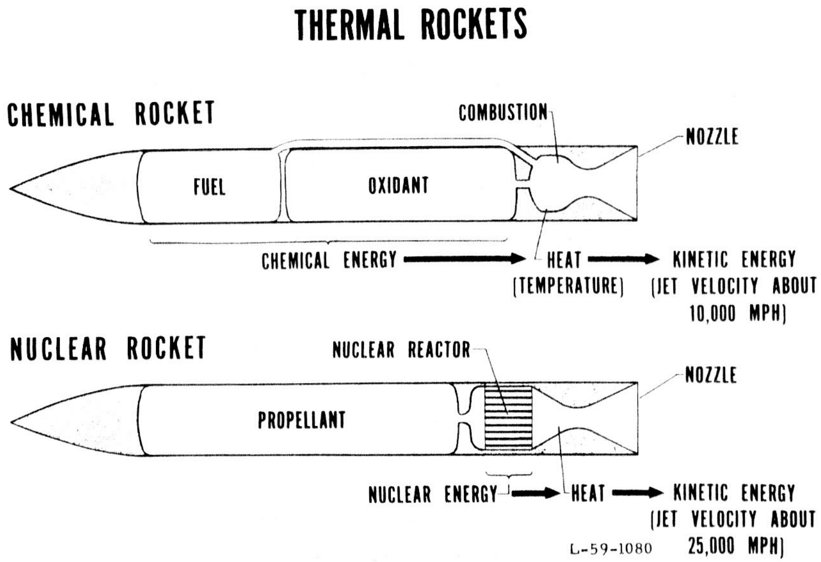


Figure 9.

[redacted]

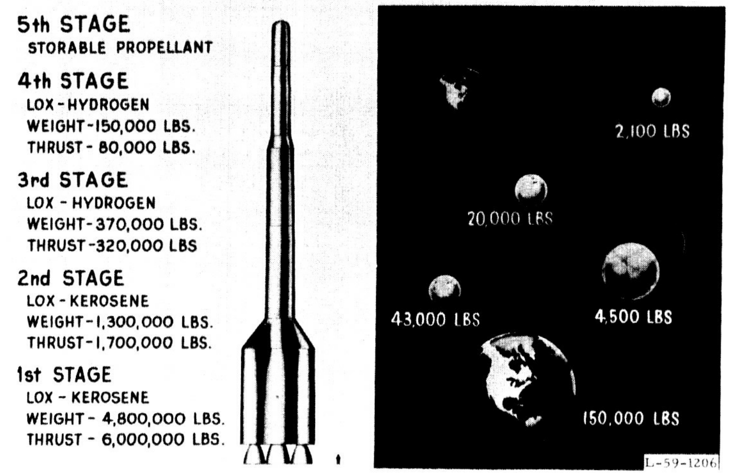


Figure 10a.

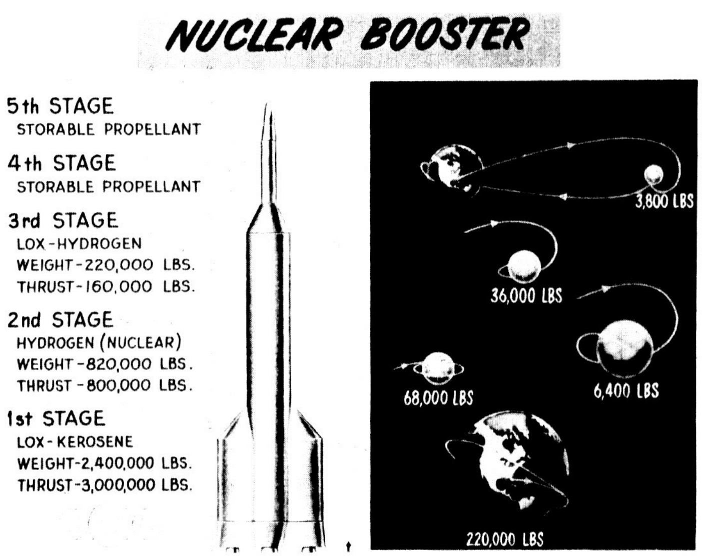


Figure 10b.

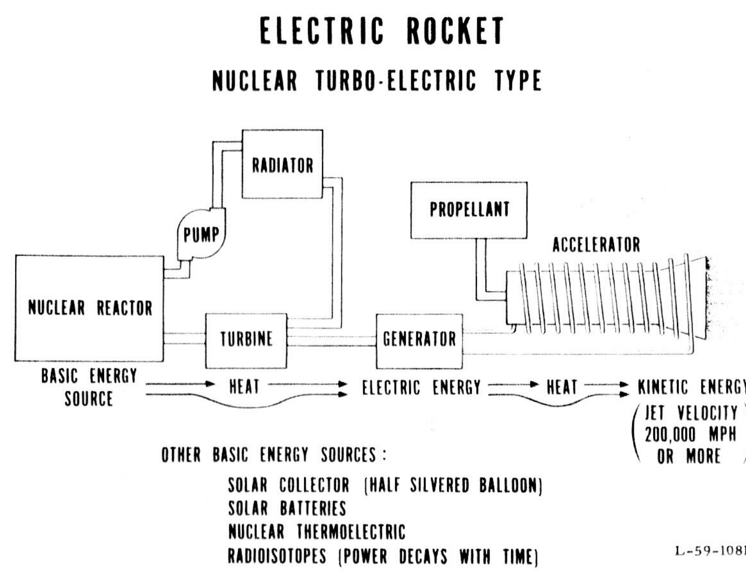


Figure 11.

PROPULSION SYSTEM PERFORMANCE

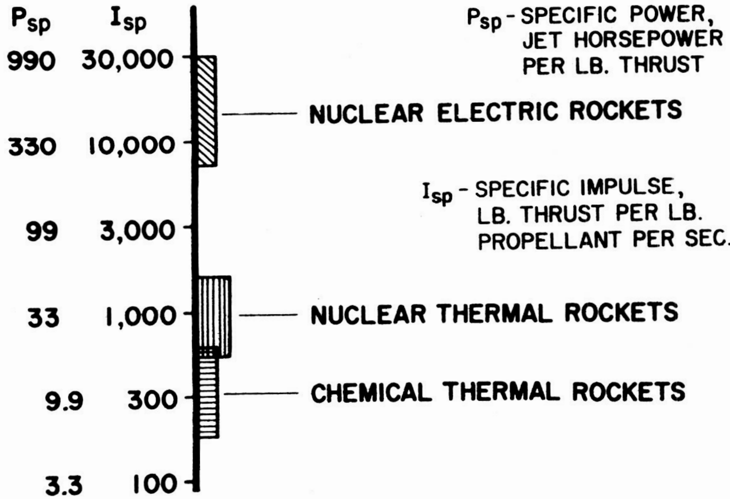


Figure 12.

ELECTRIC SPACE VEHICLE

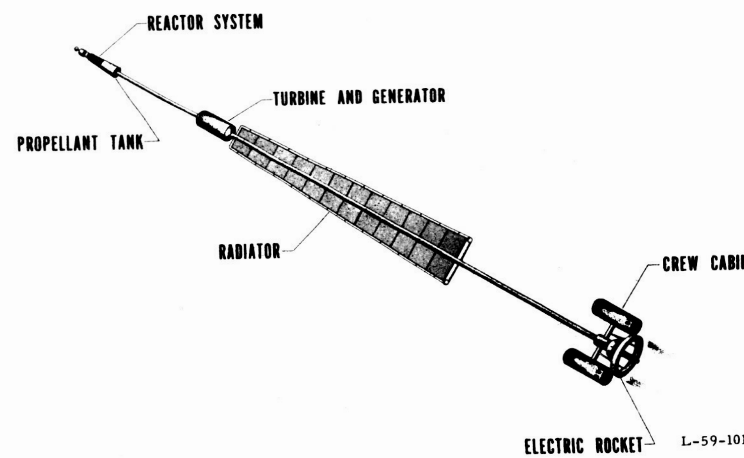
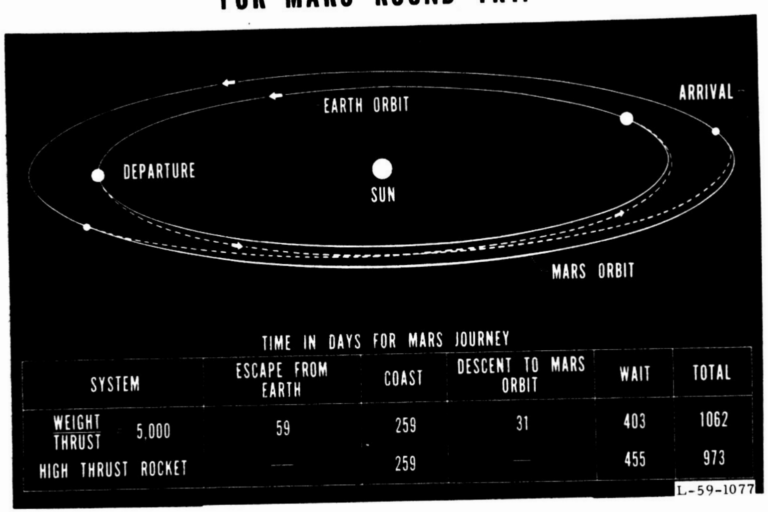


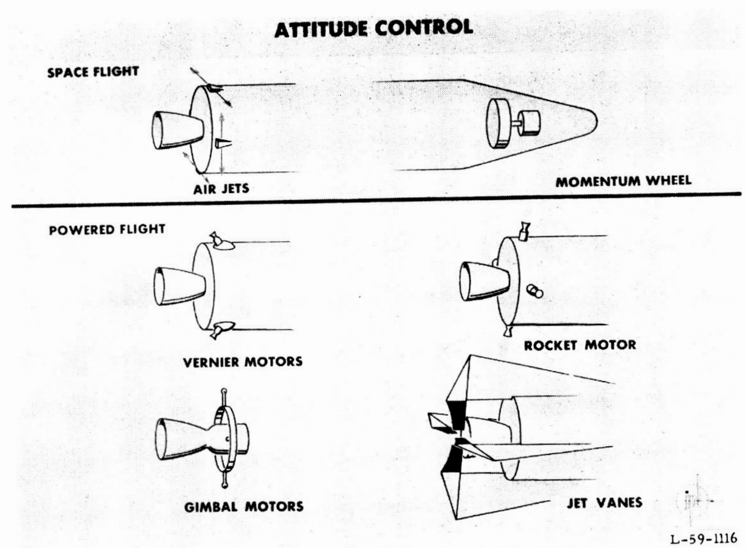
Figure 13.

MINIMUM-ENERGY FLIGHT PATH FOR MARS ROUND TRIP



SYSTEM		ESCAPE FROM EARTH	COAST	DESCENT TO MARS ORBIT	WAIT	TOTAL
WEIGHT / THRUST	5,000	59	259	31	403	1062
HIGH THRUST ROCKET		—	259	—	455	973

Figure 14.



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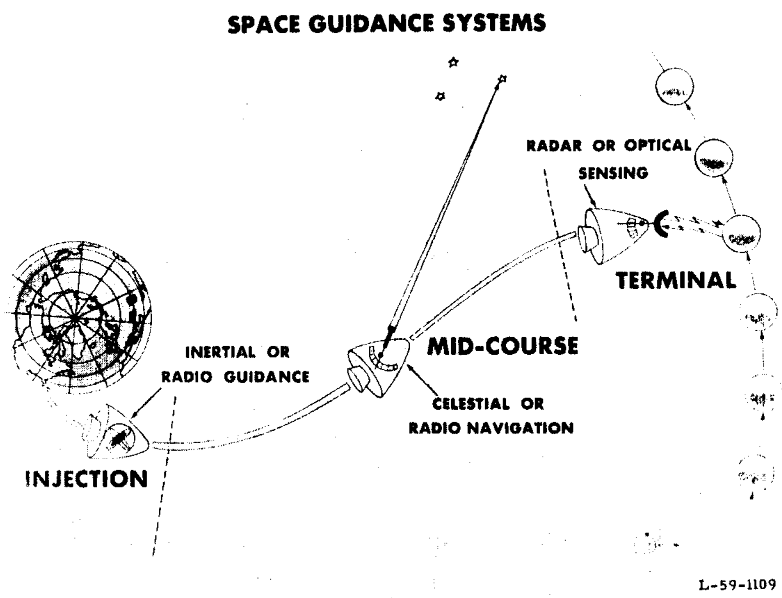

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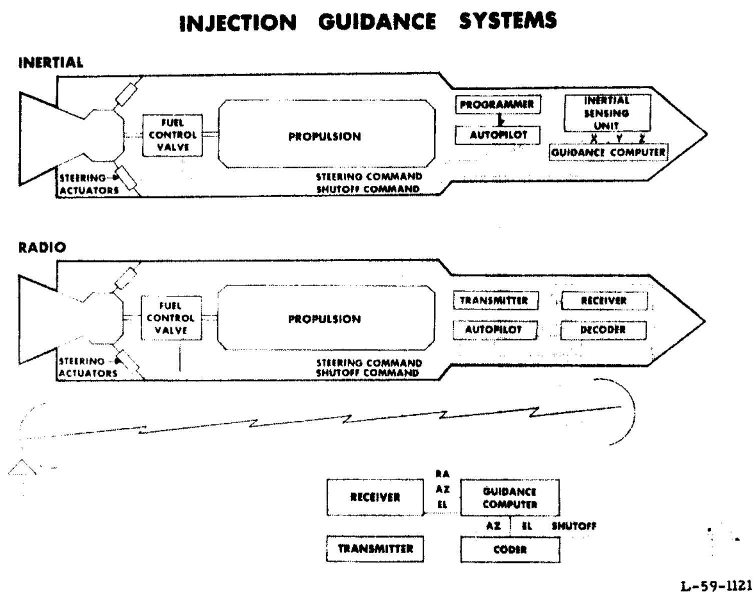

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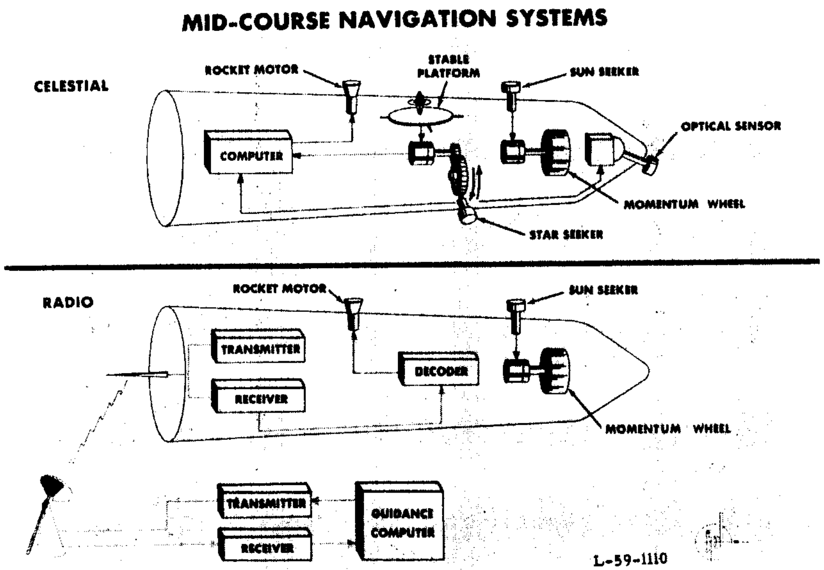

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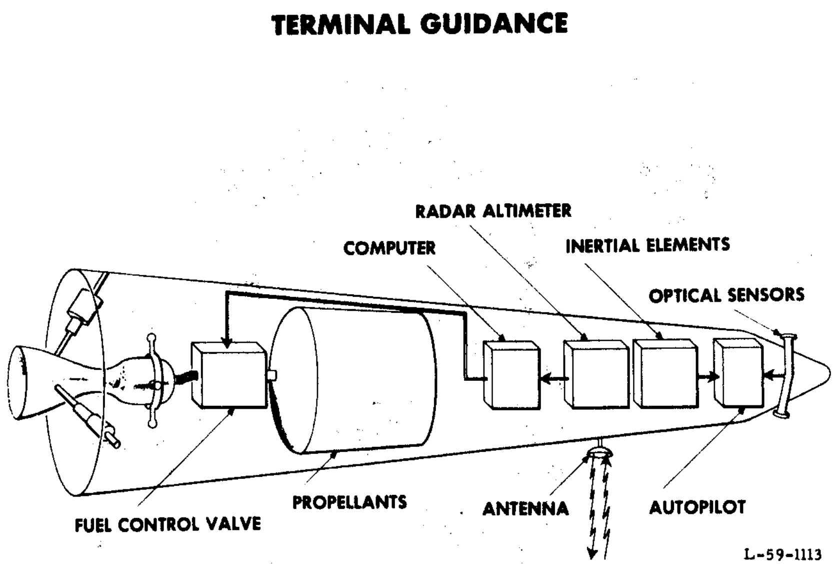

Figure 19.

INJECTION GUIDANCE REQUIREMENTS FOR SPACE MISSIONS

MISSION	INJECTION ACCURACIES		REMARKS
	SPEED, mph	DIRECTION, deg	
ROUGH LUNAR ORBIT OF 4,000 TO 6,000 MILES FROM THE CENTER OF THE MOON OR HARD IMPACT SOMEWHERE ON THE MOON.	7	0.3	MODERATE REQUIREMENTS OF AN INERTIAL SYSTEM.
PRECISE LUNAR ORBIT 600 TO 900 MILES ABOVE THE SURFACE OF MOON.	3	0.01	A FAST TRAJECTORY. MID-COURSE GUIDANCE MAY BE USED.
SOFT LANDING WITHIN 100-MILE DIAMETER CIRCLE ON THE MOON.	0.13	0.03	A SLOW TRAJECTORY, MID-COURSE GUIDANCE ESSENTIAL.
INTERPLANETARY INJECTION TO WITHIN 50,000 MILES OF MARS.	3	0.02	MID-COURSE AND TERMINAL GUIDANCE REQUIRED TO LAND OR MAKE CLOSE APPROACH.

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Figure 20.

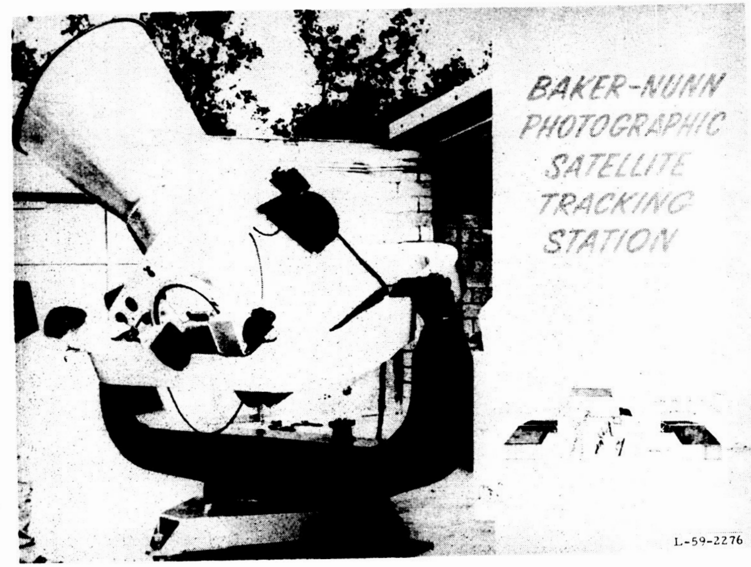


Figure 21.

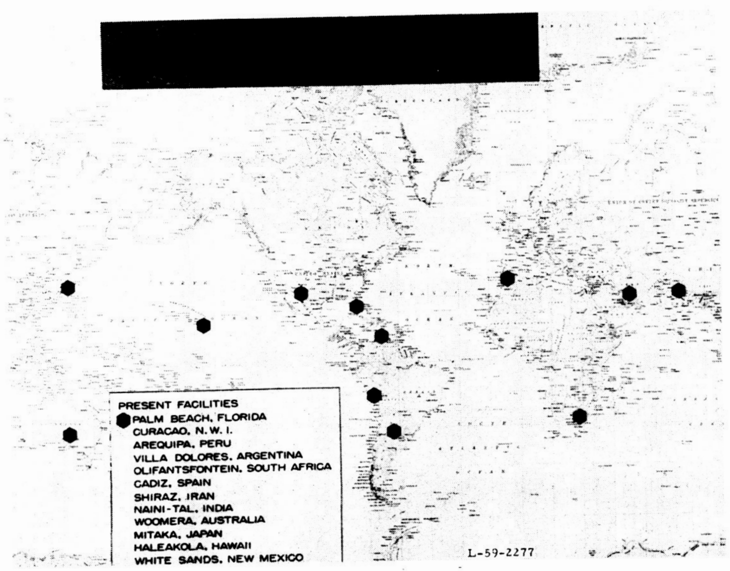
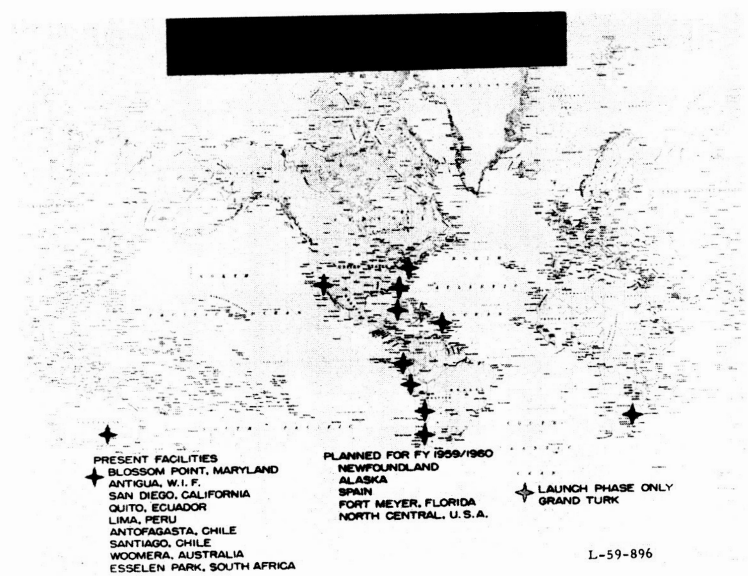


Figure 22.



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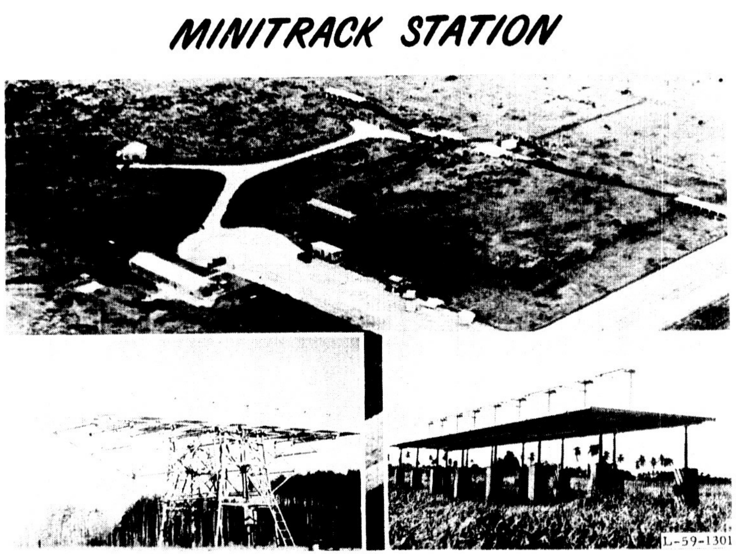
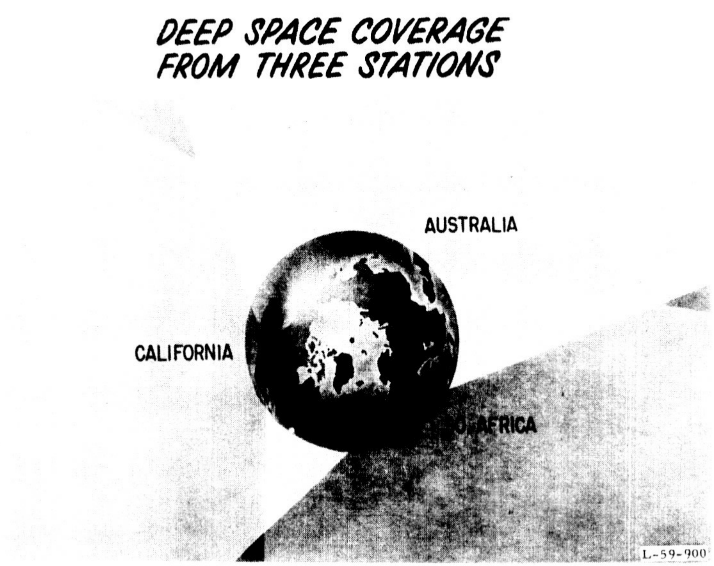


Figure 24.

Figure 25.



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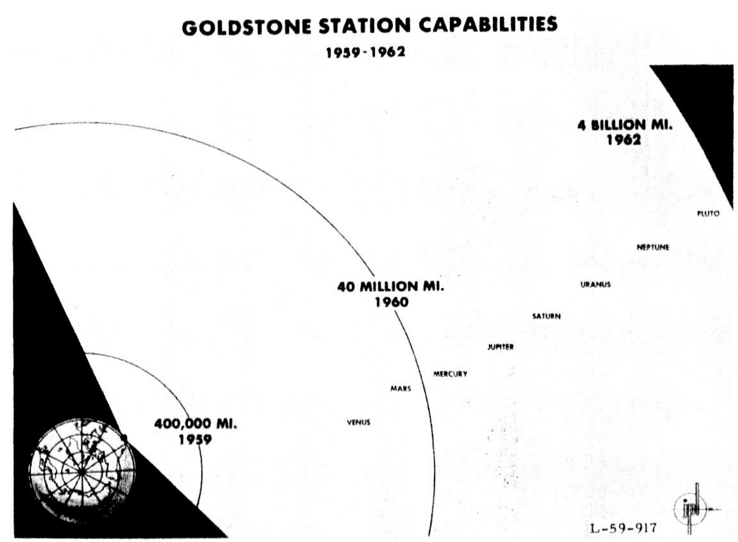
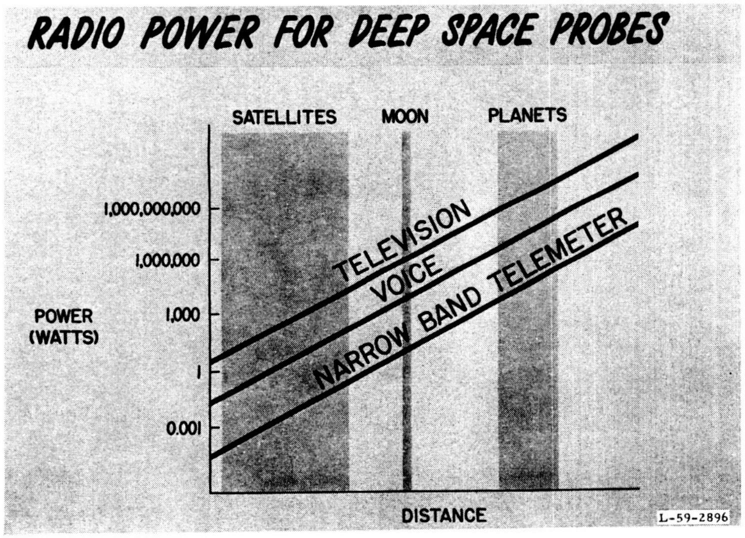


Figure 27.



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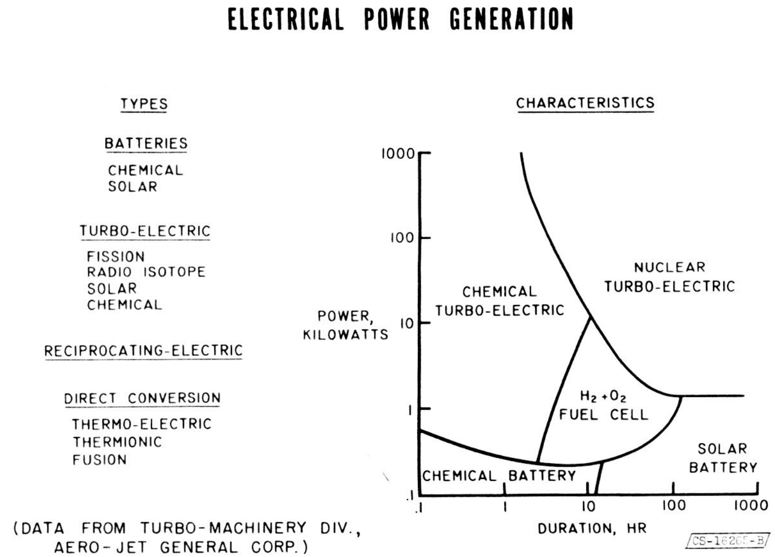

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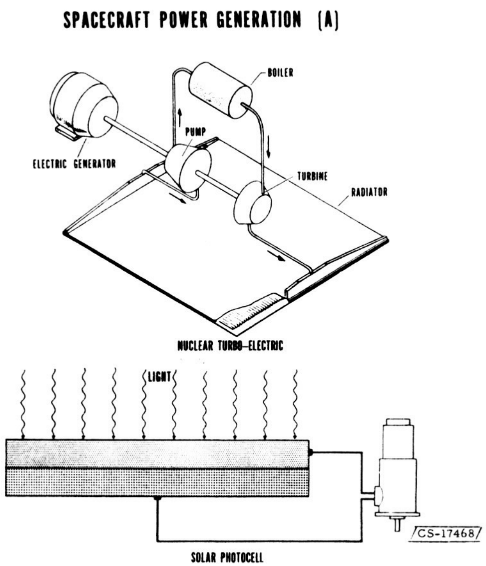

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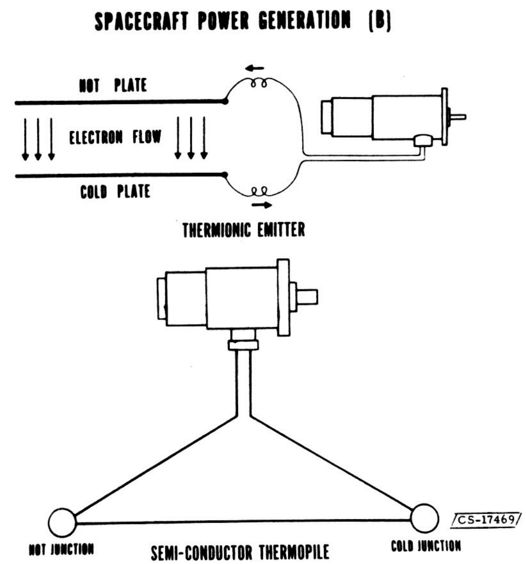


Figure 31.

SPACE SCIENCE AREAS

GEODESY
ATMOSPHERES
IONOSPHERES
ENERGETIC PARTICLES
ELECTRIC AND MAGNETIC FIELDS
GRAVITY
ASTRONOMY
BIOLOGY

L-59-781

Figure 32.

EARTH'S SHAPE FROM ORBIT OF VANGUARD SATELLITE (1958β)

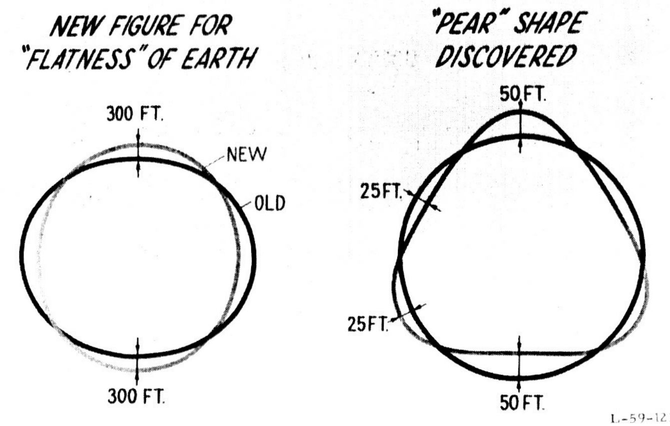


Figure 33.

CHARACTERISTICS OF EARTH'S ATMOSPHERE

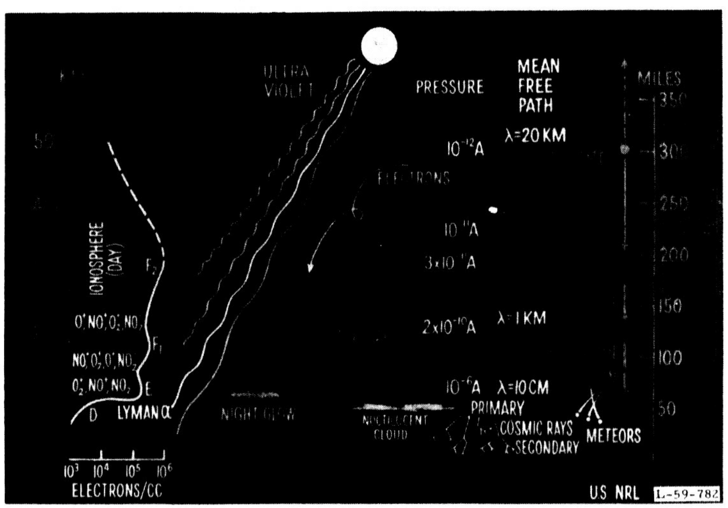


Figure 34.

IONOSPHERES

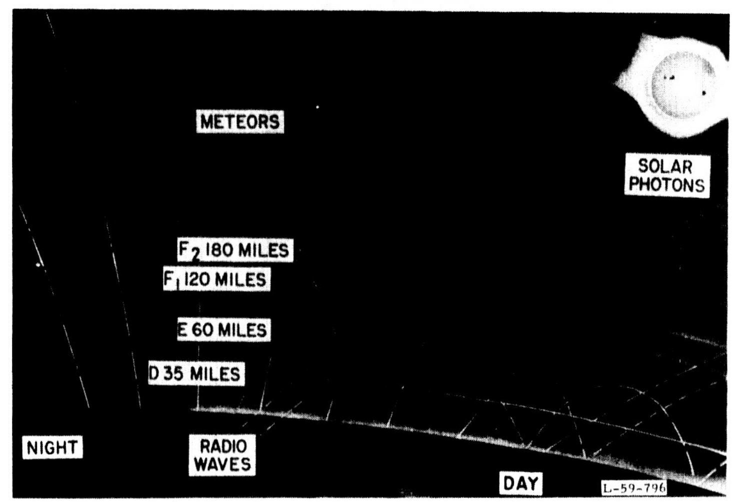


Figure 35.

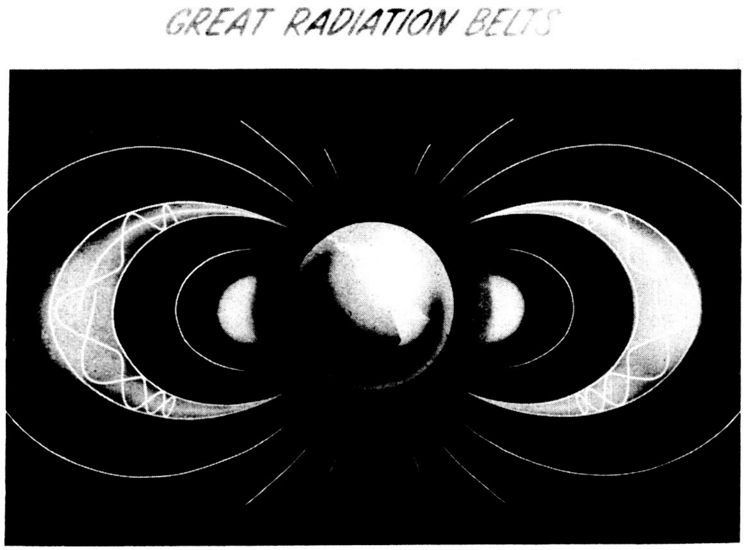
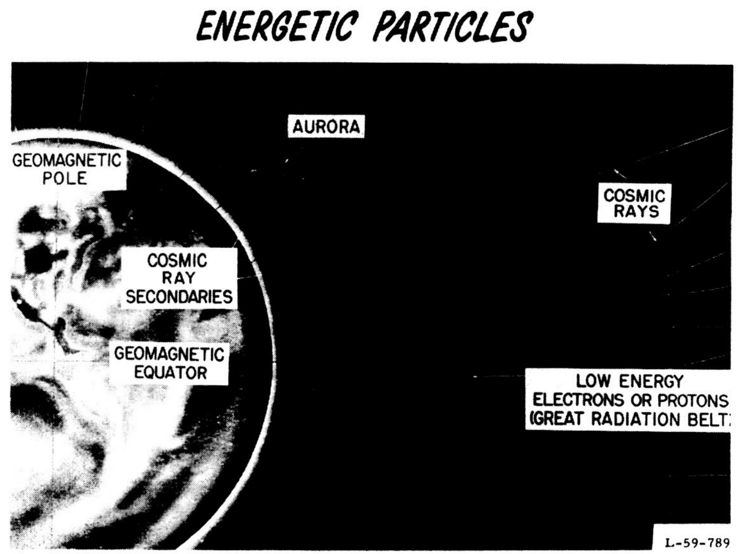


Figure 36.



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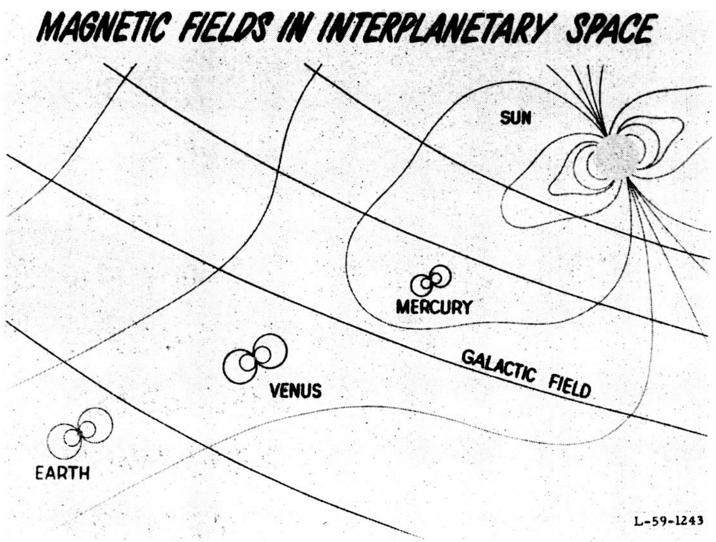

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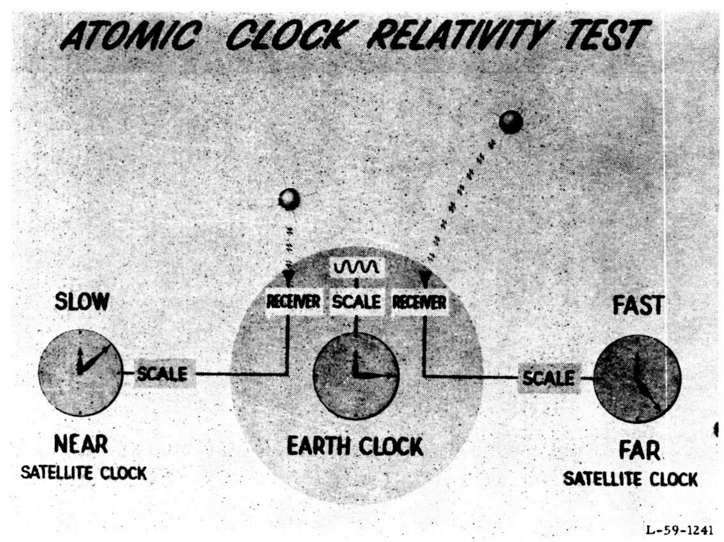

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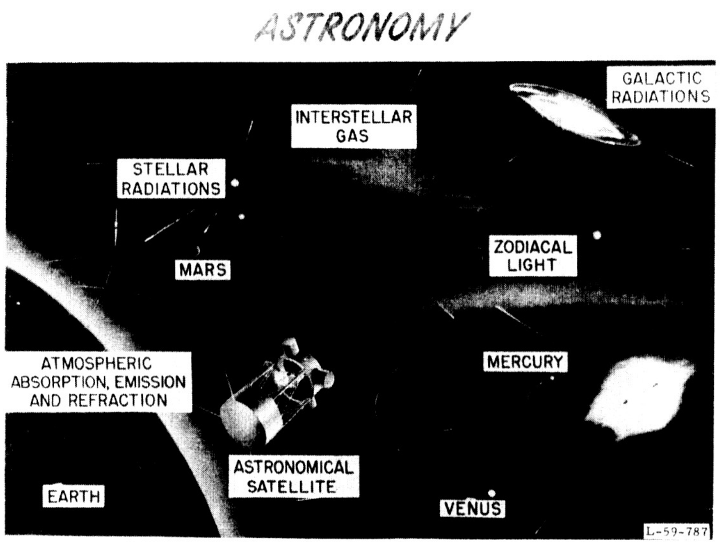

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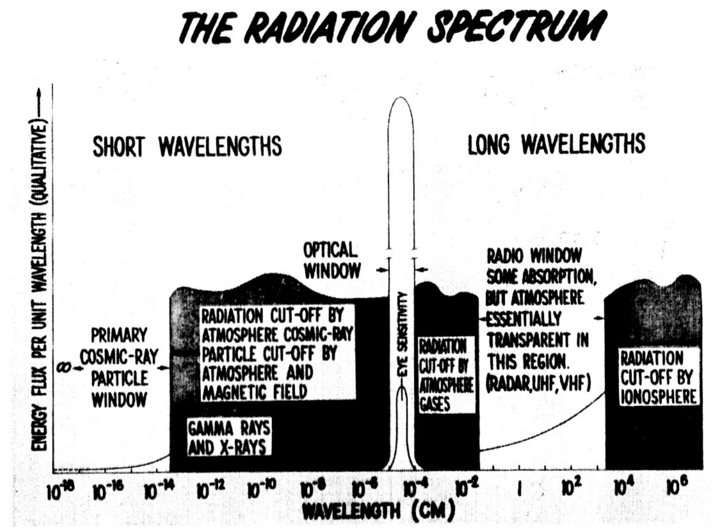

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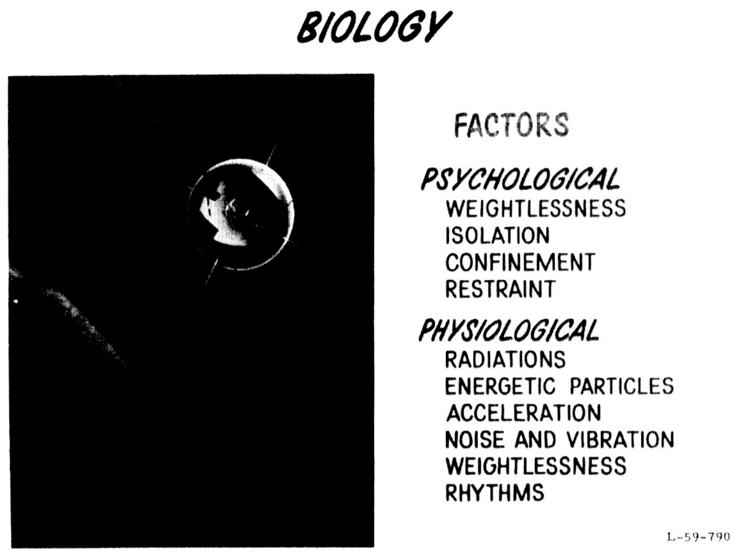

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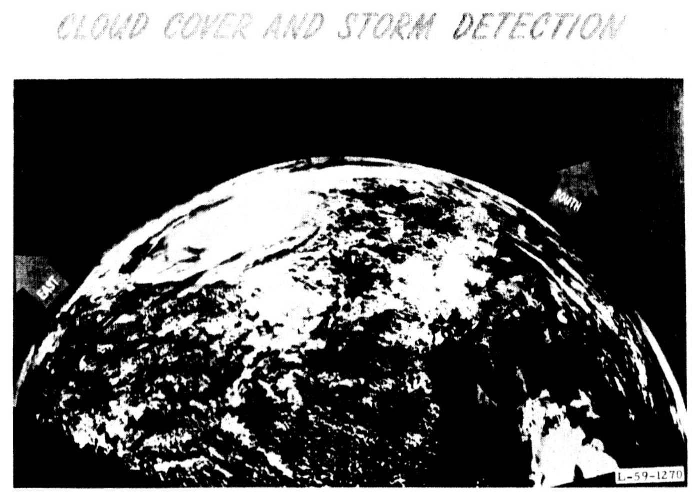

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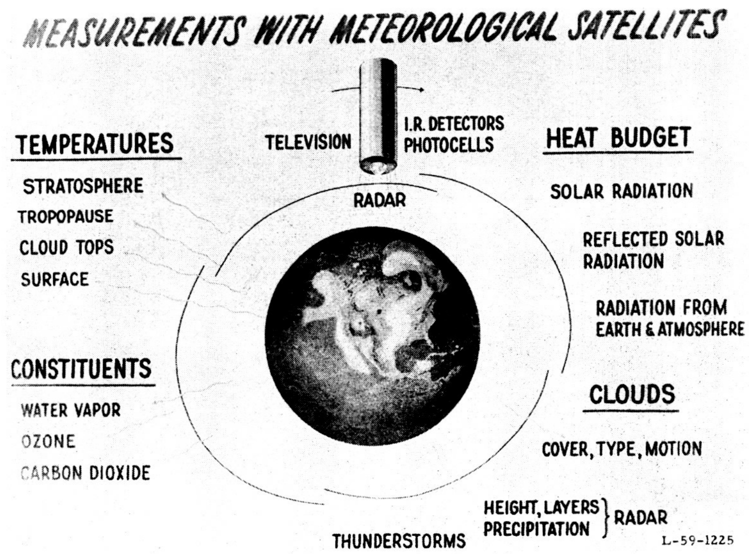

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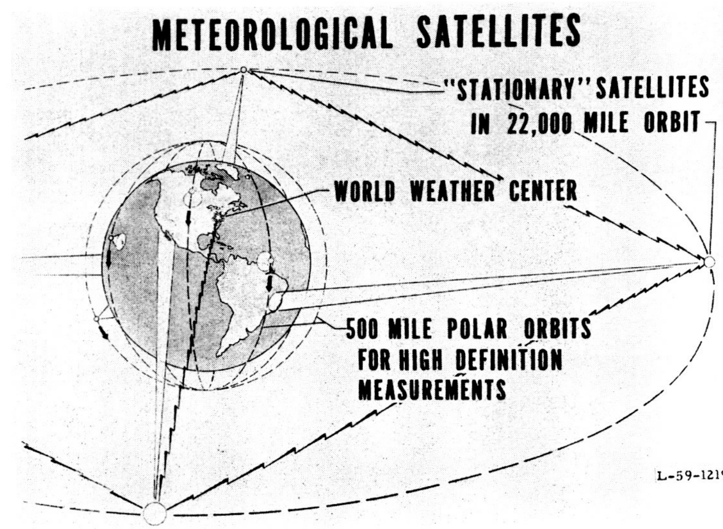

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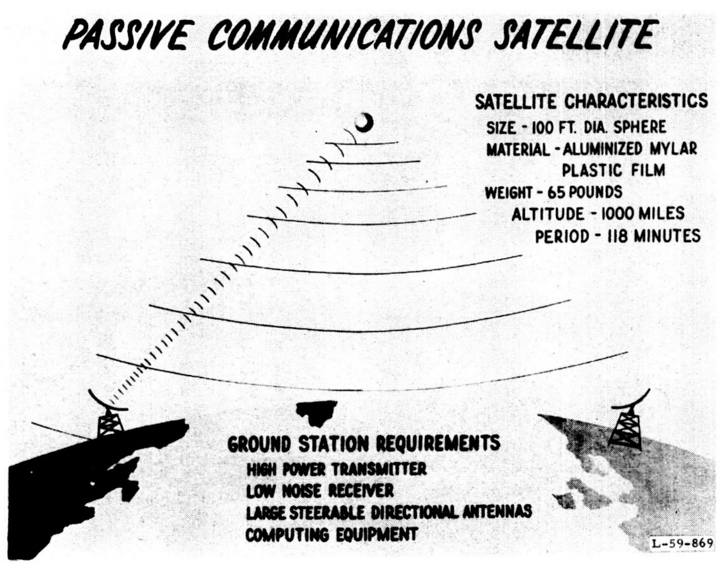
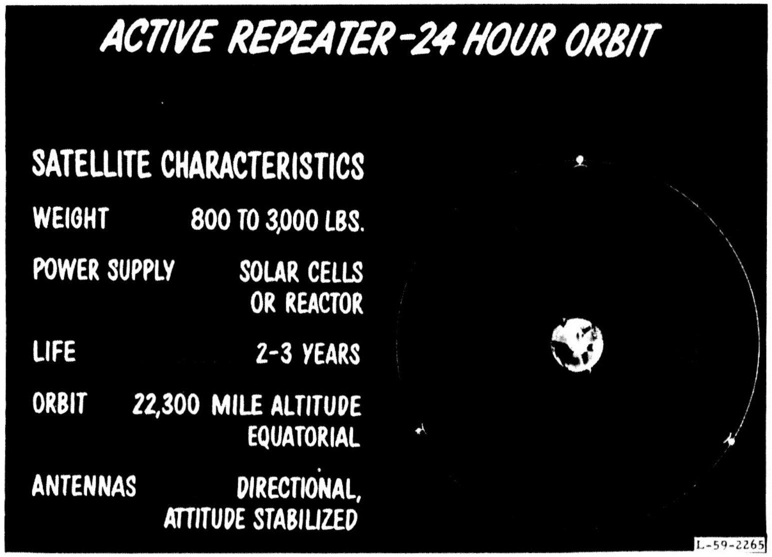


Figure 46.

Figure 47.



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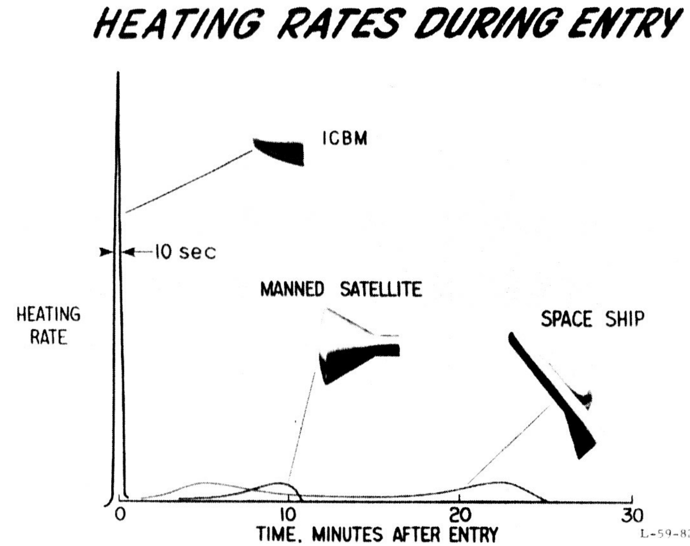

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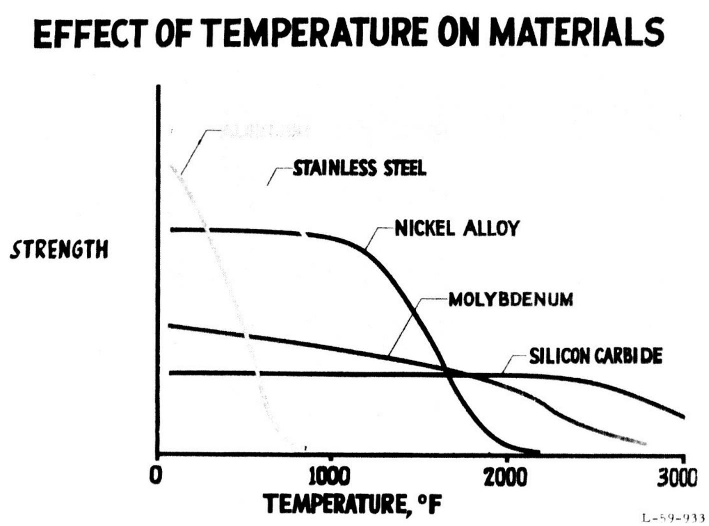

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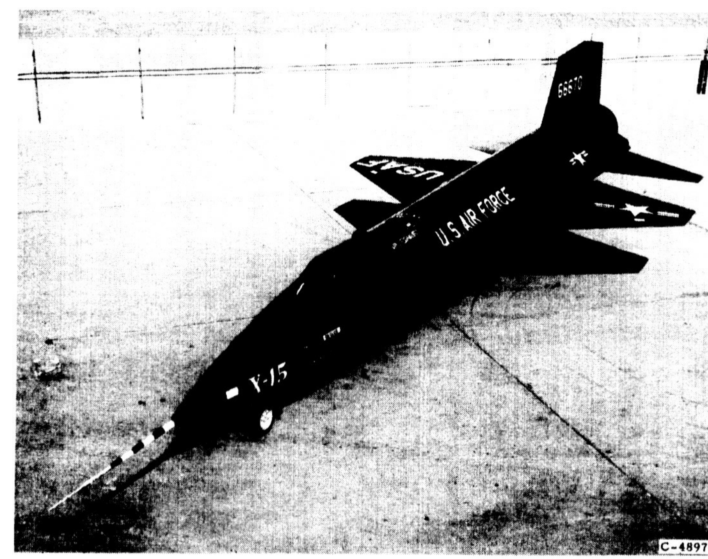

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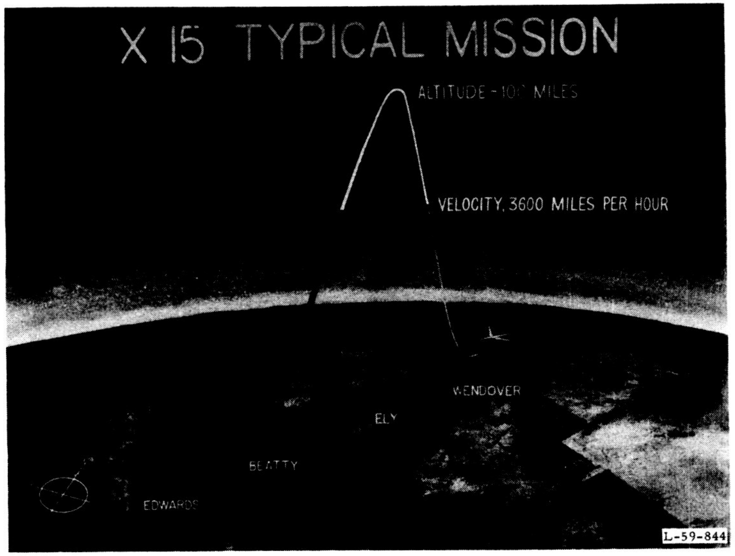

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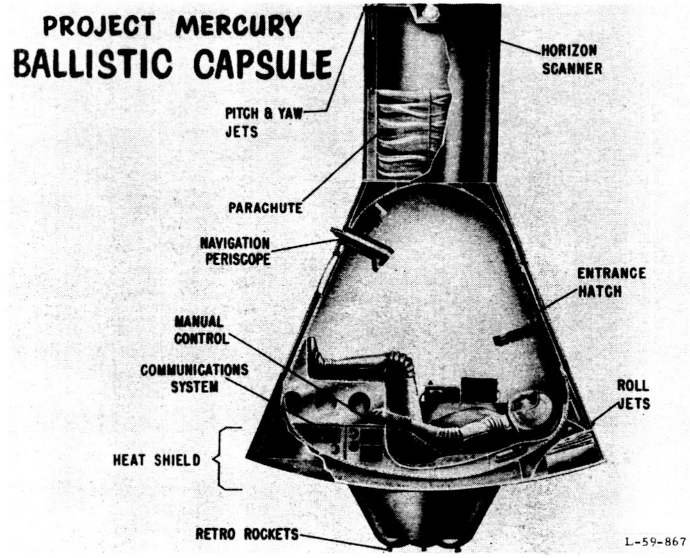

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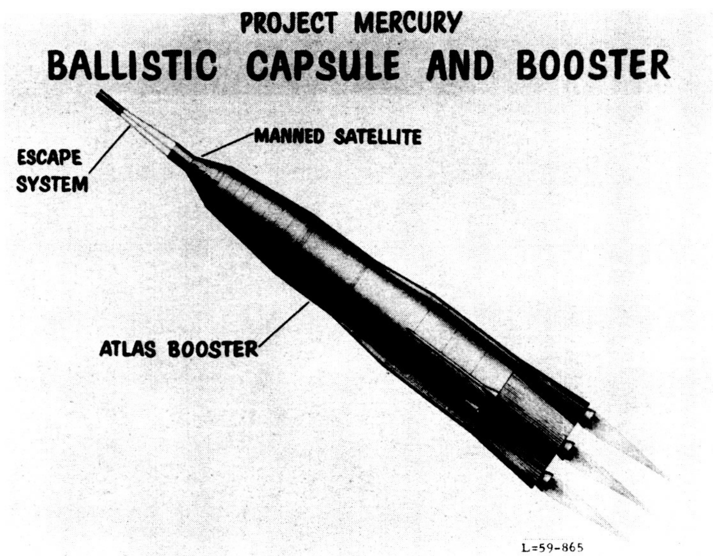

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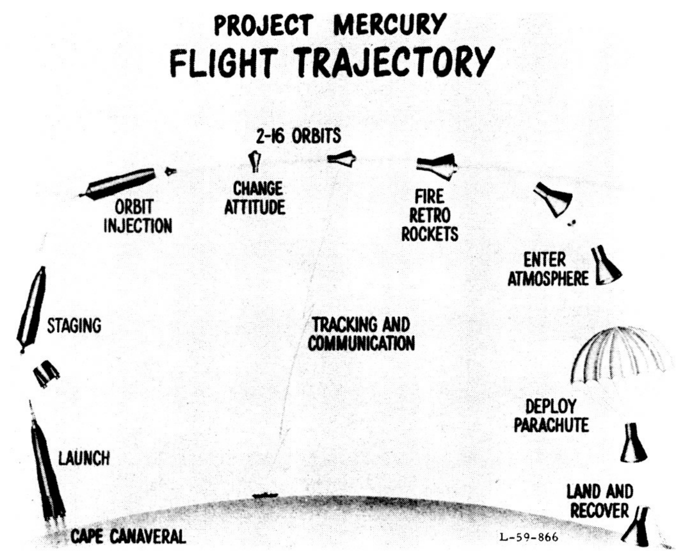

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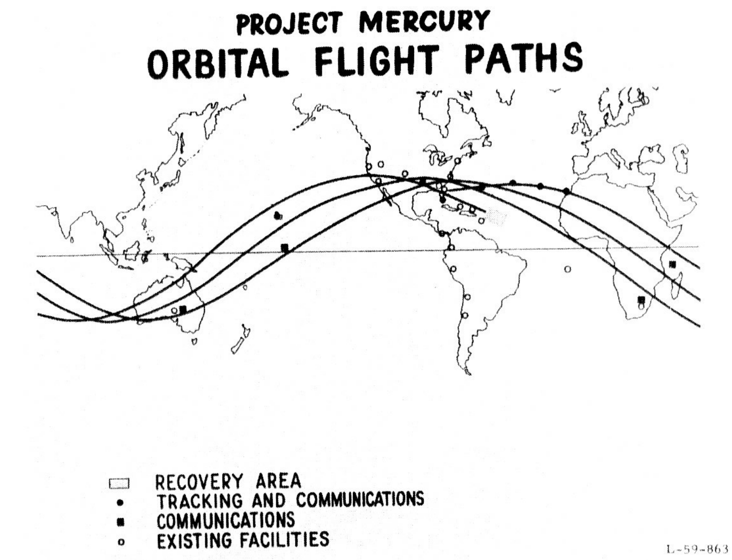

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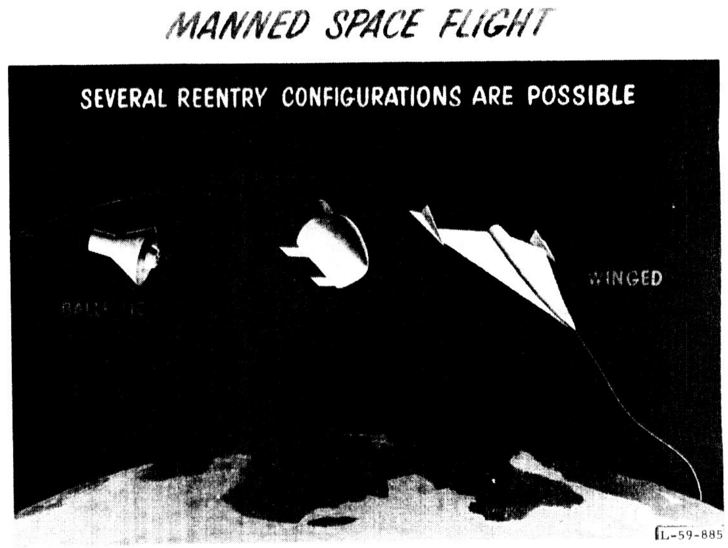

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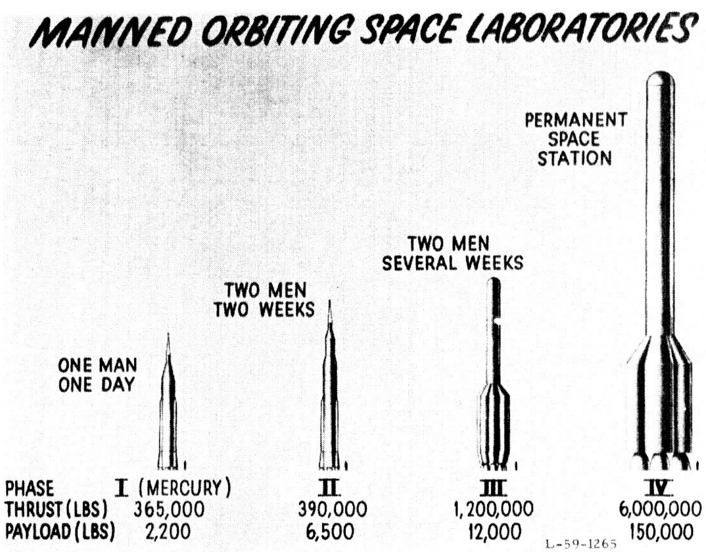

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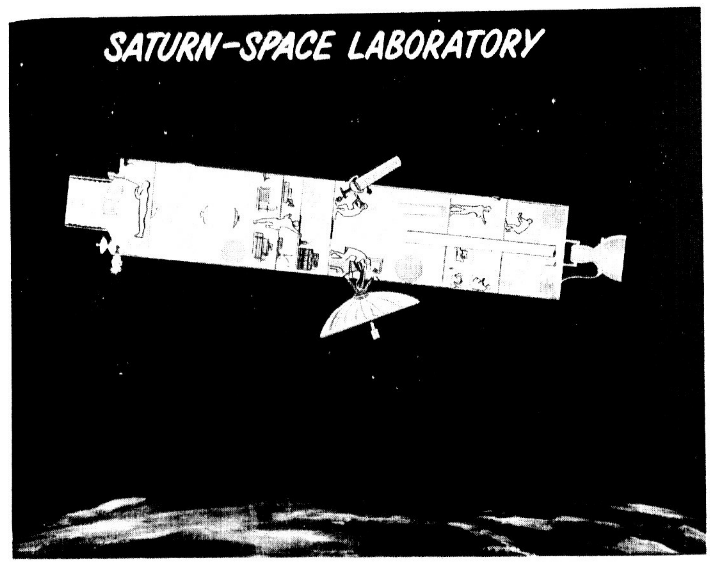

Figure 59.